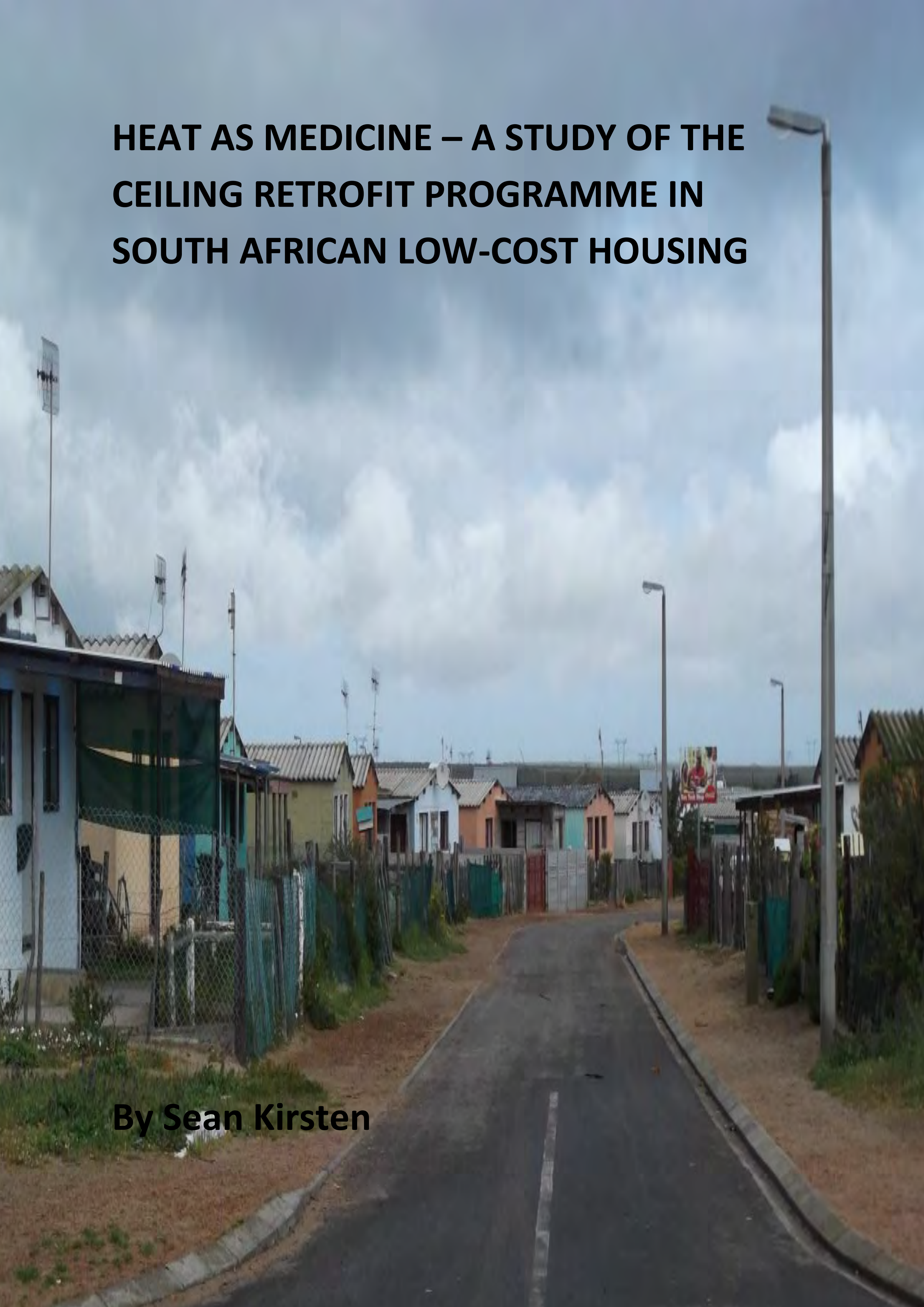
HEAT AS MEDICINE – A STUDY OF THE CEILING RETROFIT PROGRAMME IN SOUTH AFRICAN LOW-COST HOUSING



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Abbreviations

°C - degrees Celsius

ANC - African National Congress

ANOVA - Analysis of Variance

ANCOVA - Analysis of Covariance

B: C - Benefits to Cost Ratio

CBA - Cost-Benefit Analysis

CDM - Clean Development Mechanism

CLO - Community Liaison Officer

CO - Carbon Monoxide

CO2 - Carbon Dioxide

CRH - Ceiling Retrofit House

CSIR - Council for Scientific and Industrial Research

DANIDA - Danish International Development Assistance

EPA - Environmental Protection Agency

EPWP - Expanded Public Works Programme

GHG - Greenhouse Gases

Gwh - Gigawatts per hour

ICLEI - International Council for Local Environmental Initiatives

IEA - International Energy Association

iEEECO™ - Integrated Energy Environment Empowerment Cost-Optimisation

IPCC - Intergovernmental Panel on Climate Change

Kwh – Kilowatt Hour

Kg – Kilogram

MEIA - Macro-Economic Impact Analysis

NCH - Non-Ceiling House

NERSA - National Energy Regulator of South Africa

NPV – Net Present Value

Ppm - Parts Per Million

RDP - Reconstruction and Development Programme

RETROFIT- Retrofitting refers to the addition of new equipment or features to older structures/dwellings

SABS - South African Bureau of Standards

SCCP - Southern Cape Condensation Problem

SWH - Solar Water Heaters

TB - Tuberculosis

t - Tonne

UNFCCC - United Nations Framework Convention on Climate Change

UN - United Nations

U-value - rate of transfer of heat

W/m^2K - Watts per metres squared Kelvin

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Declaration

This work has not been previously submitted in whole, or in part, for the award of any degree. I have used the Harvard referencing guide for citation and referencing. Each significant contribution to, and quotation in, this thesis from the work(s) of other people has been attributed, and has been cited and referenced. This thesis is my own work. I have not allowed, and will not allow, anyone to copy my work.

Signature: Date: 13th May 2015

Signed by candidate

1. Introduction

Through the ages, energy has been the lifeblood of economies and households. However, energy abundance in the 21^{st} century is not guaranteed, and energy poverty is a growing concern around the globe. Energy poverty is defined by the International Energy Agency (IEA) as a lack of access to modern energy services including household access to electricity and clean and safe cooking facilities. According to the IEA, about 1.3 billion of the world's seven billion people have no access to energy, while another 2.7 billion are without clean and safe cooking facilities, using coal and wood for domestic tasks. With rising energy prices, higher levels of unemployment, poor housing quality and energy inefficient structures, energy poverty may become exacerbated in the near future. Often these energy-poor households cannot satisfactorily heat their living spaces and have difficulty paying energy bills. The impact of energy poverty is thus felt the most by low-income households and communities. This negative impact includes poor thermal comfort, increased sickness and mortality, reduced productivity and poor educational outcomes (IEA, 2011).

There are a number of government interventions that can assist in reducing the burden of energy poverty. These include electrification programmes, energy efficient alterations to houses, social tariffs to reduce energy prices and income-supplementing energy payments. There is an emerging body of literature indicating that energy saving and efficiency can be the most effective intervention in addressing energy poverty. In South Africa, where there is a disconnection between reducing energy poverty and providing clean energy, energy efficiency has the ability to achieve social and economic goals by reducing greenhouse gases and energy poverty simultaneously. Thus, the impact of energy efficiency in the low-cost housing sector can be substantial, given the need to uplift and empower energy poor residents (Winkler et al, 2002). With the growing consensus that greenhouse gases need to be curbed and more stringently monitored, energy efficient houses will have the added benefit of reducing carbon emissions whilst promoting sustainable development.

In evaluating the effectiveness of energy saving and efficiency intervention programmes, one needs to take into account the co-benefits that arise from the intervention. These benefits may include: job creation, productivity increases, housing value increases, reduced demand for energy, reduced emissions, improved health, improved community appearance, improved community pride and social cohesion. Despite being difficult to measure, studies have repeatedly linked improved health to energy efficient interventions. The difficulties in measuring these co-benefits include trying to monetise these benefits, the double counting of benefits, and the problem of determining causality between programmes and co-benefits. Developing better models that can capture these co-benefits will improve policies and decision making in the area of energy efficiency (IEA, 2011). Using cost-benefit analysis (CBA) to model the net benefits accruing to a particular energy saving and efficiency intervention will thus form a core component of this paper.

Exploring the energy saving and efficient intervention options available to governments, Winkler et al (2002) measured the energy cost-benefits of different interventions in low cost housing across South Africa. These interventions included installing insulated ceilings (retrofitting), roof insulation, partitions, wall insulation, window insulation, solar water heaters (SWH) and compact fluorescent lights (CFL's). Of these interventions, wall insulations and ceiling installations were the most cost-effective interventions. This approach was coined "Heat as medicine" by Howden-Chapman (2011) and a CBA conducted by his team concluded a 2:1 benefit to cost ratio (B:C) from the insulation process (IEA, 2011). Mathews and van Wyk (1996) found that by installing a ceiling in a low cost house, a 74% saving in energy consumption can be made during winter and Spalding-Fecher et al (2002) found a R781 saving in energy per year per household from ceiling installations. With ceilings having such a substantial cost-effective impact on energy efficiency, this paper will be focusing on the ceiling retrofitting intervention in addressing energy poverty. Surprisingly, solar water heater interventions offer a much smaller net benefit, as a result of high installation costs and increased usage of water. Having attended conferences on this topic and engaged with low-cost house residents in the Western Cape, the SWH intervention is often seen by the households as a luxury item, which they would happily exchange for more direct benefits such as ceilings and affordable and energy-saving cooking stoves.

With many low-cost houses lacking ceilings in South Africa, ceiling retrofitting has become an important avenue in addressing energy poverty and energy efficiency. This thesis aims to answer the following question:

- Do retrofitted ceilings in low-cost houses make a measurable difference in the quality of health, lifestyle and energy consumption, when compared to houses without ceilings?

The primary objectives will be to:

- Measure this difference using quantitative and qualitative surveys.
- Build a CBA model that puts a monetary value to this measurable difference between ceiling and non-ceiling low cost houses.
- Compare the measurable differences between ceiling and non-ceiling low-cost houses to previous studies conducted.

We aim to conclude that retrofitted ceilings are in fact, "heat medicine".

The sample group consisted of 60 households from Mamre, a small community in the Western Cape. Mamre was chosen as the community comprises of low-cost houses with retrofitted ceilings and low-cost houses without ceilings.

This thesis will provide invaluable evidence to the City of Cape Town's ceiling retrofitting programme. With this study, future retrofitting may well be motivated for Mamre and the

Western Cape. For the City of Cape Town, this further research is important in informing policy makers how they can support low-income communities within a framework of limited financial resources. Energy poverty remains one of the city's biggest challenges and interventions such as insulated ceilings may provide a way to approach the multifaceted nature of economic disadvantage experienced by communities such as Mamre, whilst at the same time addressing sustainable development.

2. Energy efficiency review

This literature review will look at energy poverty, health poverty and urbanisation before focusing on housing from around the world. The next paragraphs will look at, specifically, South African housing and then narrow down to the important topic of ceilings and various ceiling intervention programmes in South Africa.

2.1. Energy poverty

An estimated 2 billion people worldwide, predominantly in rural developing country areas, continue to suffer from energy poverty. Most of the world's energy poor are to be found in the rural areas of South Asia and Sub-Saharan Africa, where energy poverty manifests itself in the lack of access to safe, clean fuels and the reliance on mainly traditional energy sources such as biomass (Munien & Ahmed, 2012). The largest contributor to energy poverty is low-incomes and, to a lesser extent, the quality of houses. The definition of an energy poor household is, according to the IEA (2011), a household that spends more than 10% of their income on energy. Energy poverty may further be defined by the following underlying indicators: the absence of sufficient choice in accessing adequate, affordable, reliable, quality, safe and environmentally sound energy to support development (Winkler, 2009). Energy poverty thus remains one of the major challenges facing developing countries (Sagar, 2005). Energy poverty reduction is less about technology and more about understanding the role that energy plays in people's lives and responding to the constraints in improving livelihoods.

In China, South and East Asia, 675 million people had no access to electricity in 2009, and in Sub-Saharan Africa the number without access was 585 million, despite a slight increase in the rate of electrification (IEA, 2011). The consumption of modern energy per capita in these regions above is very low in comparison to that of developed countries. Moreover, the gap between these regions and developed countries has widened over the past 17 years. In Africa, the consumption of modern energy has risen, but this increase is well below the growth rate of economic output (Kaygusuz, 2011).

Alleviating energy poverty offers strong synergies with climate change mitigation agendas. If one can reduce greenhouse gases (GHG) whilst reducing energy poverty, two goals can be achieved with one intervention. According to global and regional estimates, buildings (including residential houses) offer the largest and most cost-effective mitigation potential (Ürge-Vorsatz & Herrero, 2012). Reducing a building's energy consumption is generally seen as the low-hanging fruit of climate change mitigation (IPCC, 2007). In particular, decreased heat loss through better insulation (ceilings) is suggested as one of the most cost-effective means to achieve the ambitious national and international goals of climate gas reduction (Müller & Berker, 2013).

The magnitude of energy poverty described above gives a clear indication that there is an urgent need to provide sustainable houses that exert less pressure on natural resources and that are climate resilient. This is particularly critical in the case of low-cost housing, which has often resulted in standardized housing blocks duplicated around a country that disregard local climatic conditions and energy consumption patterns, potentially resulting in energy poverty and/or increased use of energy. The problems with this standardisation concept include: the lack of information, lack of policy co-ordination, low levels of literacy, lack of access to mass media, and split incentives between builders, owners and tenants where contractors for the mass housing programmes are pressed to build the largest number of houses at the lowest cost, forsaking energy conservation (Spalding-Fecher et al, 2002). Going forward, there should be minimum international construction standards for insulation and a retrofit programme for existing houses; including insulation in ceilings, walls, roofs and energy-efficient lighting (Moye & Horne, 2013).

The energy performance of the dwelling has been identified as one of the key factors to propel households out of energy poverty whilst contributing to reducing GHG emissions. One of the solutions, as mentioned above, is to ensure high levels of insulation in the houses of the energy poor for both warm and cold climates. Installing sub-optimal retrofits and insulation may lead to additional costs with governments revisiting retrofitted houses after a few years in order to capture the remaining potential energy savings. Rather than quick, cheap and superficial energy improvements, comprehensive energy efficiency changes may result in greater improvements in energy poverty but at a greater initial cost. The question is: whether to implement minimalistic changes like ceilings to improve energy efficiency or to wait for more funds and proceed with more comprehensive changes such as walls, floors, solar water heaters and lighting in a total retrofit programme (Ürge-Vorsatz & Herrero, 2012).

There is, however, a counter-argument to the concept of energy savings from energy efficiency via insulation. Many economists seem united in their conviction that improving energy efficiency through technological means could, by lowering the implicit price, result in increased, not decreased energy use - a rebound effect called the Khazzoom-Brookes hypothesis. This conviction is the result of over a century of theoretical discussion on resource use, and empirical evidence from historical analysis of energy use (Herring, 1999). At a micro level, energy-efficiency improvements do result in reduced energy consumption, though there is often a take-back of some of the savings, a process termed the 'rebound effect'. For instance, when insulation alterations, like ceilings, are improved in low-income households, some of the energy savings (due to the higher insulation levels) are taken back in the form of higher comfort levels and energy expenditure (Herring, 1999). Thus residents may end up buying more appliances with the energy savings. Recent surveys of the literature in industrialised countries have shown that the take-back effect for residential space-heating is relatively small, in the order of 10–30% (Spalding-Fecher et al, 2002). State of the art interventions like solar and wind energy may thus reduce the rebound effect through substantial energy savings. For space-heating in developing countries, however, one can expect a larger rebound since poor consumers are often unable to keep their homes comfortable, both because they cannot afford the fuels and appliances and because the quality of the housing is so poor. Spalding et al (2002) found a take-back of 50% of the savings from energy efficiency in developing countries. This take-back effect needs to be incorporated into models on energy efficiency.

Additionally, rising incomes have a positive impact on energy consumption. Daiogloua et al (2002) used a model to focus on detailed projections for residential energy use in India, China, South East Asia, South Africa and Brazil. These countries/regions were selected due to their importance for global energy use as newly industrialised and developing economies. In most of these regions, cooking was the dominant household function. As households became richer, energy use for appliances, space heating/cooling and water heating gained in importance. In China and South Africa, space and water heating were projected to become more important, given the cooler climatic conditions. In contrast, space cooling was expected to be more important in India, South East Asia and Brazil. The projections showed how useful energy demand increased with increased affluence in these regions (Daiogloua, van Ruijven & van Vuuren, 2012).

2.2. Health poverty

Respiratory diseases have consistently been among the most prevalent diseases in developing countries. For example, in addition to being one of the leading national causes of mortality in Kenya, respiratory diseases were also the leading cause of hospital admissions in all Kenyan provinces (Ezzati & Kammen, 2002). With the exception of tuberculosis (TB), diseases of the respiratory system have received mixed attention in developing countries despite their public health importance. Air pollution has often been overlooked due to the over-emphasis of diseases linked to germs (Ezzati & Kammen, 2002).

On the global burden of disease risk factors, indoor air pollution ranks third at 4%, after malnutrition (16%), and poor water and sanitation (7%). Indoor air pollution is currently responsible for over 1.6 million deaths each year – more than 4,000 deaths per day. The global cost of this burden to national health care systems, not reflected in the price of energy, is a striking $212 billion to $1.1 trillion. Furthermore, by 2030, deaths from indoor air pollution are projected to be greater than those from malaria, TB, and HIV/AIDS (Sovacool & Dworkin, 2012). Childhood acute lower respiratory infection remains the single most prevalent cause of death for children aged less than 5 years in developing countries (Bruce, Perez-Padilla & Albala, 2000).

Using data from 85 demographic and health surveys conducted under the auspices of the United Nations, Montgomery and Hewett (2005) estimated that only one half to two thirds of urban households in Latin America, North Africa, sub-Saharan Africa, and many parts of Asia had sleeping rooms. The recent mass migration of families from rural to urban areas in developing countries has increased concerns about the quality of housing. There is evidence that poor ventilation, often associated with inadequate flooring, wall composition, and roofing/ceilings, is connected to poor indoor air quality and an increased likelihood of respiratory illness. The evidence suggests that poor housing quality poses a risk for children's health - impairing both their physical and cognitive functioning (Bradley & Putnick, 2012).

The Human Development Index, a combined index of life expectancy, education, and income from 127,347 households in 28 developing countries, was found to have a significant positive correlation with the quality of housing. The great difficulty with the high number of low-quality home environments in poor countries is that they contribute to the intergenerational transmission of poverty and poor quality of life. This evidence supports the need for a concerted effort to focus on the quality of houses.

Increasingly, medical reports are emerging linking poor health to energy poverty and to poor quality houses. Mould and condensation linked to humidity are particularly troublesome, causing asthma in children. This asthma is notoriously difficult to cure. Approximately 15% of children in IEA member countries suffer from asthma. Energy improvements can also improve mental health with stress levels notably decreasing in energy efficient houses (IEA, 2002). Cold homes tend to make people feel irritable and sick, spend more time away from home and not invite people to visit, often resulting in a social breakdown, which is hard to measure (IEA, 2011).

Living in poorly constructed houses with inadequate facilities, warmth and ventilation not only poses a direct threat to children's health and competence, but makes the tasks of parenting more difficult (Bradley & Putnick, 2012). In the field of healthy development, household energy is thus vital. This is consequently a very important field for energy efficiency interventions, and one in which technical and policy research needs to be closely linked to development work in a range of countries and settings.

Regarding CO_2 levels in houses, the symptoms caused by CO_2 intake are directly related to the fact that an increasing CO_2 level causes decreasing oxygen levels in the body, hampering the flow of oxygen to the brain. Outdoor CO_2 levels are typically around 380 to 500 parts per million (ppm). If the concentration of the gas is still relatively low, common symptoms include headaches, an increasing pulse rate, fatigue and breathing difficulties. When the concentration of the gas reaches a level above 30,000 ppm, symptoms can include heavy nausea, dizziness or vomiting. At these levels, asphyxiation or a loss of consciousness can also occur. However, this is unlikely to occur in a common house, where levels of CO_2 usually range from 300 to 2,000 ppm (Propex, 2014). The US Federal Government considers any concentration of CO_2 above 5,000 ppm as dangerous, although the US Environmental Protection Agency (EPA) warns that indoor ventilation is inadequate at CO_2 levels of 1,000 ppm and above (EPA, 2013).

2.3. Urbanisation and green houses

The increasing trend of urbanisation is placing substantial pressure on housing in developing countries. Recently, the overall global number of urban dwellers has surpassed rural dwellers. This trend is set to continue to increase with two thirds of the population expected to be in urban dwellings by 2050 (UN Habitat, 2011). During the last 50 years, the urban population of developing countries has increased by 600%, highlighting this tremendous pressure. The Latin American region is the most urbanised globally, with 76% of the population living in cities in 2000. This figure is expected to increase to 85% by 2030 (Moye & Horne, 2013). Within the next 25 years, around 53% of Africans are expected to live in urban dwellings, with more than 300 million new urban dwellers by 2030. The UN-Habitat estimates that around 3 billion people will need access to housing over the next 25 years globally. This will require 35.1 million housing units per year (assuming 4 people per house), or 96,150 per day, in order to meet the demand for housing over the next 25 years (International Housing Coalition, 2007).

As cities continue to grow, increasing the access of the poor to adequate shelter will be one of the biggest challenges facing governments in developing countries. In order to meet this growing need, governments will have to explore a wide range of solutions adaptable to local conditions for housing construction, energy efficiency, financing and land acquisition.

In most developing countries, land acquisition costs are among the most expensive components of housing development. This pushes the poor to the peripheries of urban development where the land is more affordable. Builders and developers in the low-cost housing sector must accept slim profits per unit to maximise affordability. Thus, land development and housing construction is only profitable if it can be delivered in large numbers to obtain economies of scale. Nevertheless, this development is often constrained by the lack of large pieces of urban land in desirable locations (Lizarralde, 2011). Low-income housing is therefore often located in disconnected and far-off areas. This can deepen the residents' poverty trap through increased transport costs, distance from jobs and poorer public services. The demand for this subsidised housing can be dampened by providing job creation incentives and lifting the income level of poor residents in developing countries, enabling them to buy or rent property closer to the urban centres.

In order to address pollution and the growing carbon footprint resulting from urbanisation, the 2002 World Summit on Sustainable Development focused on cities. This city-wide focus is based on the evidence that the construction of the built environment is responsible for 50% of global CO_2 emissions. There is a growing consensus that cities and buildings will play a massive role in the future of the green economy. Transport, food supplies and buildings account for 60% of the energy used by the global economy, according to a United Nation's environment programme. This weighting brings into sharp focus the importance of the technical design of buildings and their construction in an effort to conserve energy (Sustainable Development Network, 2013).

Often addressing the carbon footprint is seen as the preserve of the wealthy and affluent; as design changes to make buildings green and energy efficient are costly once-off expenses. However, this 'once-off model' only takes a single point in time approach instead of a life-cycle approach, which incorporates the costs and savings over the lifetime of a building and the increasing costs of materials due to inflation. With the once-off approach, it is only the well-off who can afford the changes, however the life-cycle model brings these changes into the domain of the low-cost household. This life-cycle model makes sense as it is important to take into account the full operational costs and benefits of a given process over the lifetime of the process. A house should thus be seen not only as a noun but as a verb too. A house is a flow of energy, activities and services over the lifetime of that building and moves beyond mere material (Sustainable Development Network, 2013).

Housing is responsible for as much as 25% of global operational energy demand. This makes targeting the residential sector, one of the most cost-effective and vital areas for CO_2 emission reduction. Improving household energy efficiency and consuming more renewable energy is a way to address the multifaceted hub of environmental and social problems. It is commonly held that the cost of investing in household energy efficiency is often smaller than the gains realised over the medium to long-term from resultant energy savings, as these energy savings lead to reduced energy and CO_2 generation (UN Habitat, 2012). UN Habitat (pg. 23, 2012) proposes that to reduce energy demand and the carbon footprint from residential buildings, a range of solutions can be used:

- Planning and enhancing the orientation of buildings (north facing), as well as improving walls and roofs (by paint or greening), in order to use the opportunities provided by passive heating, lighting and active shading.
- Better insulation of the structural parts of houses - walls, ceilings, windows, floors, doors, roofs - in line with better ventilation (keeping houses warmer in cold periods and colder in hot periods).
- Installing energy efficient appliances for heating, cooling, cooking, lighting and ventilation.
- Developing local low-carbon power plants that service housing (based on joint heat and power generation and renewable electricity generation).
- Arming houses with renewable electricity or heat generating units such as heat pumps and solar water geysers.
- Reducing energy-intensive building materials and technologies used in homebuilding.
- Incentivising and correcting household energy consumption patterns through energy metering and billing.
- Capacity building activities and marketing to raise awareness of the importance of energy savings and how it can be achieved.

2.4. Housing from around the world

In Latin America, despite improved growth rates and high rates of house ownership, economic disparities, the prevalence of slums, and the quantitative and qualitative deficit of the housing stock present challenges for governments (Moye & Horne, 2013). Low-cost housing constitutes an ongoing challenge in Brazil as costs must be kept to a minimum (around $3,000–4,000 per house). Considering Brazil's large housing deficit (estimated at around 7 million houses) and limited financial resources, the housing problems are far from over (Grigoletti, Sattler & Morello, 2008).

Chile has one of the lowest housing deficits in Latin America. Their housing policy is considered by international agencies, such as the World Band and the Inter-American Development Bank, as a best practice model. Chile's current housing policy allows for private and social organisations' involvement in the process of providing housing (Moye & Horne, 2013).

Due to energy insecurity as a result of earthquakes and droughts, the Chilean government has focused on reducing energy demand through energy saving publicity campaigns, with an overall goal of reducing demand by 12% by 2020. In the 2011 government statistics, the building sector accounted for 26% of total electricity demand in Chile, out of which 77% of the energy consumption corresponded to residential buildings (Moye & Horne, 2013).

A CBA study in Chile has indicated that relatively low-cost improvements to the house design can provide significant energy savings. The subsequent sensitivity analysis supported the argument for its cost-effectiveness, even with increasing energy price and energy demand scenarios. Of particular interest is the potential increase of energy demand due to increased incomes. As low-income communities overcome poverty, the purchase of electronic devices and comfort features will potentially lead to a higher consumption of energy. Energy efficiency awareness campaigns and education will be crucial to avoid this counter-productive impact on the communities (Moye & Horne, 2013).

When looking at housing in an African context, in Morocco the building sector accounts for approximately 36% of final energy consumption, with 29% of the energy consumption linked to residential buildings. This energy consumption is expected to increase in view of major projects currently being initiated and planned by the government in key sectors of the Moroccan economy. A dynamic energy study, using software for an individual house located in Oujda City, was conducted by Guechchati et al (2012). Results show by using 6cm of thermal insulation to the outside of exterior walls, annual heating required energy is reduced by 8.4% and the annual cooling required energy is reduced by 70.5%. The window area plays an important role in building energy consumption in the Moroccan environment. Replacing the single glazing by double glazing on the windows can achieve a saving of 1.9% in annual required heating energy and 6% in annual cooling required energy for the base case house (Guechchati et al, 2012).

China is aiming to meet the goal of 50% energy savings in buildings by focusing on energy efficiency. The cost of building shells is 12.7% of the total building cost in China. Improving building insulation capacity is about 6% of the total civil engineering cost (Gu et al, 2005).To deal with the environmental challenge of climate change mitigation, the Chinese government mapped out their 11th Five-Year Plan (2006 - 2010), which laid out a roadmap for the country's sustainable development. Energy efficiency was an important part in the plan. A total of ten energy-saving programmes were presented with the energy efficiency of buildings being one of them (Gu et al, 2005).

In China, income levels and energy expenditures indicate that energy carries a high budget burden for the poorest households, contributing more than 10% to the household budget (Munien & Ahmed, 2012). Although the Chinese government has established a policy for energy efficiency, it no longer has the power to guide the property market that it had several decades ago. Before 1978, almost all buildings were planned, funded and constructed by the state. Today, most of the Chinese housing developments operate under market-based principles (Gu et al, 2005).

The public mass housing strategy in China is a typical top-down provider model. In the provider strategy, the providers, mostly governments and corporations, produce houses for residents according to mass production principles: centralised, standardised, industrialised and instant. Generally, the residents have little choice and they cannot influence the building designs as they wish. In contrast, the opposite model is a support enablement strategy. In this strategy, the supporters do most of the work by themselves. The benefits of this model are: decentralised, varied, handmade, locally influenced and incremental, with more focus on energy efficiency. The key for the provider model is thus regulation to promote energy efficiency (Gu et al, 2005).

There are thus few developers creating energy-efficient buildings in China. Each developer has a set of strategies for a project and developing energy-efficient buildings should be one of these. This strategy would improve the market attractiveness of the project, but it does increase the costs and financial risks. If one developer in the Chinese construction industry produces energy efficient buildings, but others do not, the more costly energy efficient project will likely fail in price competition. Thus, all developers adopt strategies that simply provide the minimum standards in energy matters, establishing the Nash equilibrium (Nash, 1950). The most effective method of dealing with this situation is to increase the required standards through national regulations. However, because of the great diversity of developers, it is difficult to introduce very strict energy-efficient regulations for residential buildings, even in developed countries, let alone in current China. In this situation, architects could take responsibility for energy-efficient housing developments with the right incentives (Gu et al, 2005).

2.5. South Africa's low-cost housing programme

As mentioned above, the percentage of the global population living in urban areas is expected to increase, with remarkable growth in Sub-Saharan Africa. South Africa is no exception, with the migration being largely driven by poverty. Those seeking access to the economic opportunities that cities provide, often live in informal settlements. As these settlements grow, a significant burden is placed on the local municipalities and service delivery is often compromised. The South African government, alongside municipalities, such as the City of Cape Town, and a range of other partners started a programme of formal housing construction for low-income and vulnerable households. This is known as the Reconstruction and Development Programme (RDP). The RDP is a South African socio-economic policy framework implemented by the African National Congress (ANC) Government in 1994. The ANC's chief aim in developing and executing the RDP was to address the vast socio-economic development backlog, a consequence of Apartheid (ANC, 2013).

State-built houses have been under construction in South Africa since the Apartheid era and have continued to be built into the democratic period. Between 1994 and 2012, over 3 million government subsidised low-cost houses were built, accommodating 5 million of the estimated 12.5 million South Africans previously without proper housing (Phillips, Silver & Rowswell, 2011). Some communities have become disgruntled with the poorly built, serviced and designed houses. In addition, their inaccessibility, corrupt allocation and long delay in delivery have heightened these frustrations. This has created a very hostile and explosive environment, with many uprisings across the country regarding these state-supplied houses (Phillips, Silver & Rowswell, 2011).

With regard to environmental factors linked to low-cost housing, the South African government ratified the United Nations Framework Convention on Climate Change (UNFCCC) in August 1997. While South Africa does not currently face any limits on emissions under the Convention and the accompanying Kyoto Protocol (an international agreement signed in Kyoto linked to the UNFCCC), its emissions intensity (the amount of emissions per unit of economic output) is among the highest in the world and more than triple that of many industrialised countries. Given that almost 80% of these greenhouse gas emissions relate to fossil fuel combustion in the energy sector, using energy more efficiently in housing must become a priority, particularly with millions of houses still to be built (Spalding-Fecher et al, 2002).

Moreover, as international funding for climate change mitigation projects develop, it is important for the South African Government to identify project concepts that meet local social and economic goals whilst benefiting the global environment. One such example is through the Clean Development Mechanism, a mechanism that provides space for emission reduction projects that can trade their credits on a global level (UN Habitat, 2011). Projects with economic benefits for the country tied to reduced GHG emissions are called 'no regret' projects. The South African government has identified these as a priority, according to the White Paper on Energy Policy, stating that the Government will follow a 'no regrets' approach in the energy sector which includes housing (Department of Minerals and Energy, 1998).

The question remains whether the South African Government will be able to build sufficient houses through the RDP. The funds are not available to build housing for all poor urban citizens, neither for squatter residents in the city, nor the increasing number of migrants. Many state-led housing programmes around the globe have set extravagant targets and fallen short of them. In many cases, like in Europe and India, government-funded housing programmes have fallen short of their stated objectives (UN Habitat, 2008). The rate of urbanisation and rural-urban migration in most developing countries is just too rapid, the numbers too large and the need for low-cost housing too overwhelming. Experience has shown that it costs 10 to 15 times more to construct new housing than it costs to upgrade the housing, living locations and settlements in which people have already lived and thus have already invested (UN Habitat, 2008). Public funds may be better spent on upgrading the existing stock of inexpensive housing and executing a range of pioneering and dynamic methods to create new stock. Therefore, there has been a shift to address the current houses and shack dwellings and a focus on improving these ahead of building brand new houses.

By its own admission, the South African Government requires R58 billion to fix the sub-standard RDP houses currently in stock. This process will take approximately 40 years, based on an annual allocation of R1.3 billion for the renovations (Impumelelo, 2013). This requires a focus on addressing the existing housing stock whilst ensuring that new houses are built to better standards.

Since 1994, the South African National Department of Housing has implemented two very distinct policies. The first policy was the 1998 White Paper on Housing, which provided a capital subsidy to drive housing delivery (Department of Housing, 1998). This policy resulted in the construction of millions of houses for the poor. However, the subsidy included the budget for the land portion, which meant the urban poor who received houses were allocated to the outskirts of town, far from work and services, to save on the land portion of the costs. This amplified the Apartheid legacy of low income housing being located on the outskirts of cities and provinces (Sustainable Development Network, 2013).

Since 2004, the second policy was adopted, known as Breaking New Ground (Department of Housing, 2004). This policy focused on integrated interventions to bring about unified human settlements rather than disconnected squatter camps. It included sustainable development as one of its pillars (Sustainable Development Network, 2013).

The design working life of new houses under Breaking New Ground is required to be 30 years. The housing construction is stipulated to consist of an area of $40m^2$, which includes two bedrooms, a combined kitchen/living area, and a separate bathroom with toilet, shower and basin (Sustainable Development Network, 2013). Currently, standard RDP houses have very few energy efficient interventions built in. The main reason for this is that the delivery system is contract-based for RDP houses. There is thus no incentive to make the houses efficient as the benefits do not accrue to the contractors. The contractors will look to make a profit from the development so they build only the essentials.

Previously built RDP houses tend to:

- have poor ventilation,
- face the incorrect direction (not north),
- have small windows,
- lack insulated doors, walls and floors,
- lack ceilings,
- lack plastic waterproofing throughout the structure (Winkler et al, 2002).

Picture 1: Outside of a typical RDP house in Mamre

2.6. Housing opportunities going forward

As discussed above, the urbanisation problem is growing. There are, however, a number of innovative ideas for improving informal housing in their current position and novel ways to deal with the housing backlog in South Africa, including new designs and materials.

The “I-shack” is a shack development project whereby a shack is insulated using everyday materials, like cardboard boxes, and fire retardant material along with bricks to keep them warm and safe. They are also fitted with solar panels to provide electricity for devices such as a radio, television, computer, kettle, cell phone charger or stove (Take Part, 2013). It is part of an incremental improvement process, rather than an extensive once-off new development project for the 7 million or more RDP houses planned, for which there is already an extensive backlog. The project aims to use cost-effective ways of dealing with the immediate problems of informal dwellings (Sustainability Institute, 2013).

The Lynedoch Sustainable RDP house, in Stellenbosch, is now complete. It was built using South African Bureau of Standards (SABS) approved adobe bricks in order to be registered with the National Home Builders Registration Council. It includes one of South Africa's first fully integrated direct current mini-grids, whereby the appliances within the house are all 12 volt systems that can be powered by the 425 watt solar photovoltaic panels on the roof. It has a solar hot water geyser and a 220 volt Eskom supply as a backup system (Sustainability Institute, 2013).

The Moladi system RDP house consists of a re-usable and recyclable plastic mould, which is filled with stoneless concrete and a special chemical additive. This additive ensures that, once the mortar is set, the framework can be removed and reused up to fifty times. According to the founder, Hennie Botes, the brickless walls can withstand all types of weather. In addition, the formwork is lightweight, allowing easy transportation. Due to the ease in design and the repetitive application scheme, large-scale construction costs can be reduced significantly. The Moladi model is not only cost-effective but fast too; Botes claims that the wall structure of a house can be completed within one day. A further positive factor, especially in remote areas, is that the construction does not require heavy machinery or electricity (Moladi, 2012).

Using advanced design and construction technology, the Council for Scientific and Industrial Research (CSIR) have developed a demonstration RDP house with significantly improved performance and sustainability. If built according to CSIR specifications, and on a large scale, such houses will be constructed much faster and at a similar cost to the current method. Often, standard low-income houses have no ceilings and thus no insulation, which results in incredible variations in temperatures. The thermal performance of the roof was improved with the addition of an insulation material that doubles up as a ceiling. The house faces the suitable direction ensuring bedrooms can benefit from sunlight, while the living room faces north (Engineering News, 2009).

The Kleinmond community housing project was developed in 2007 in a joint scheme between the Department of Science and Technology, the CSIR, the Western Cape Provincial Department of Human Settlements and the Overstand Local Municipality. This ground-breaking Cape Town housing project was the first to introduce modular masonry material to the construction of South African low-cost housing. Further new technologies, developed by the CSIR, include the expandable design of the house, reinforced ring beams, prefabricated plumbing, zero-waste in construction and insulated ceiling boards (Ecoblog, 2011).

A glimpse into the future of sustainable living is provided by Gyproc's lightweight building materials used to construct more energy efficient houses, which will play a central role in building a green economy. In partnership with Humane Homes and Cashbuild, they built a model "green" house in Meadowlands, Gauteng, to give people the chance to view an energy-efficient, two-bedroom, modular house. In line with international building trends, this house is manufactured off-site, and packed and shipped with as few as 28 panels. It takes only 3 days to construct (Saint-Gobain, 2013).

The Witsand community in the Western Cape of South Africa is a 20 year-old settlement of over 2,000 shacks where residents were living in poor conditions with little access to basic services. Cape Town City Council chose to transform the community using the integrated Energy Environment Empowerment Cost-Optimisation (iEEECO™) methodology. IEEECO™ features include:

- Wind turbine/solar panel hybrid power systems including solar thermal water heating units and solar energy products
- Large north-facing windows for cooling during summer months and heating during winter months,
- Plastered concrete blocks with sand-filled hollows to increase mass, leading to better insulation.

This intervention was coupled with water and power conserving appliances and fixtures within the homes, community gardens, storm-water best management practices, appropriate municipal infrastructures, ceiling insulation, fire-retardant walls and ceiling boards. Phase 1 of the development was completed in October 2010, and consisted of 452 residential sites (Peer Consultants, 2013). It led to a reduction in the demand for space heating and households were found to have benefited from the energy produced inside the unit while cooking during winter.

There are several high-profile designers working on the concept of using shipping containers as low- cost houses, workspaces, student houses and even shopping centres. Globally, container architecture is gaining momentum and evolving due to a surplus of shipping containers. In places like Los Angeles and Cape Town, there are harbours with numerous shipping containers piled up and wasting away as containers become obsolete over time due to no longer being seaworthy. However, they are still strong and suitable for housing. These steel units come in two standard sizes: 20 × 8 × 8 feet and 40 × 8 × 8 feet. Worldwide, state-of-the-art architects and builders concerned about the environment are recycling these waste products and designing low-cost houses from them. They are manufactured with heavy-gauge Corten steel to make them strong and highly resilient to the elements.

Locally, a student hostel in Simon's Town was built with forty shipping containers. Each finished container costs about R33,000 (2013 estimate) including the delivery to the building site. The system is green, easy to construct, and inexpensive, reducing the building's carbon footprint (Sea Container Homes, 2013). A second advantage is the speed of construction, at three months compared to the conventional 18 months for a similar building. The external walls can be insulated with 80mm polystyrene and plastered with 35mm plaster before being painted (Joburg, 2012).

2.7. Ceilings

In South Africa, many formal low-cost RDP houses are built with the option of installing a ceiling at a later stage. Unfortunately, many of these houses remain without a ceiling. Research has shown that, after the selection of material for an external wall, the addition of a ceiling is the most helpful intervention to improve the thermal efficiency of a house. The same research has shown that the thickness of the ceiling, whether 6mm, 8mm or 12mm, makes very little difference to the thermal efficiency. A 6mm thick plywood or gypsum plasterboard is sufficient to provide insulation. Where there previously was no ceiling, installing a standard 6mm fibreboard ceiling makes a difference to the annual space heating temperature of around 8%. Although ceilings and ceiling insulation were not found to be principally economical interventions as a once-off cost, the significant health and comfort benefits are believed to outweigh the costs of the interventions over the life time of a household considering the life-cycle model (Sustainable Development Network, 2013).

Picture 2: Inside a non-ceiling RDP house

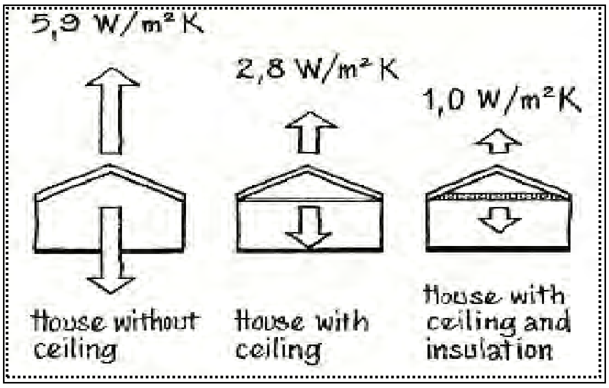
In cold climactic regions, or regions with cold winters, a ceiling can reduce space heating costs by up to 70%. The South African Department of Housing's Draft Framework on Environmentally Efficient Housing has identified ceilings as an important intervention within social housing frameworks (Sustainable Development Network, 2013). On average, annual energy savings from low-income housing with ceiling interventions in Cape Town are 296Gwh (Gigawatt hours) and in South Africa are 2,641Gwh (City Energy Support Unit, 2013). Electric power consumption per capita in South Africa was last measured at 0.004Gwh in 2009, according to the World Bank (Trading Economics, 2014). Evidence thus supports the assertion that ceilings provide a substantial energy saving.

The purported benefits linked with ceiling installations include:

- A reduction in expenditure on indoor heating and improved health as a result of improved air quality and more stable internal air temperatures.
- Increased productivity resulting from improved health and increased quality of life
- Less energy used means less CO_2 being produced (Sustainable Development Network, 2013).

In 2013, Sustainable Energy Africa conducted empirical research in the low-income housing sector and concluded that houses with ceiling and insulation are more thermally efficient than a similar house without a ceiling. The modelled benefits of this intervention indicate a 70% improvement in thermal efficiency is experienced by households. This evidence supports the theory that households with insulated ceilings require less energy for warmth. Thermal transmission, commonly known as a U-value, is the rate of transfer of heat through $1m^2$ of a construction divided by the difference in temperature across the construction. It is expressed in watts per metres squared Kelvin, or W/m^2K. Well-insulated parts of a house will have a low thermal transmission value, while poorly insulated parts of a house will have a high thermal transmission. A house with a ceiling has a U-value of 2.8 W/m^2K and with insulation and a ceiling, a U-value of 1.0 $Watts/m^2k$ compared to 5.9 W/m^2K for a house without a ceiling (see Figure 1 below).

Figure 1: Analysis of thermal efficiencies in low-income housing



Source: Sustainable Energy Africa 'Ceiling Retrofits in Low-Income Homes' www.sustainable.org.za

Mathews and van Wyk (1996) found that by installing a ceiling, a 74% saving in energy consumption can be made during winter. This is the energy saving intervention, according to

Mathews and Van Wyk, which has the most potential for formal low-cost houses in South Africa. According to their survey, 92% of the respondents would like to add a ceiling to their house, not only for thermal comfort, but also to add to the attractive and hospitable appeal of the house. The payback period for a ceiling in this study is just over 7 years, after which the ceiling cost breaks even with the benefits. This is based on an assumption of an energy cost escalation of 15% and a discount rate of 10%, for a 16 m^2 ceiling installed in the kitchen-living area.

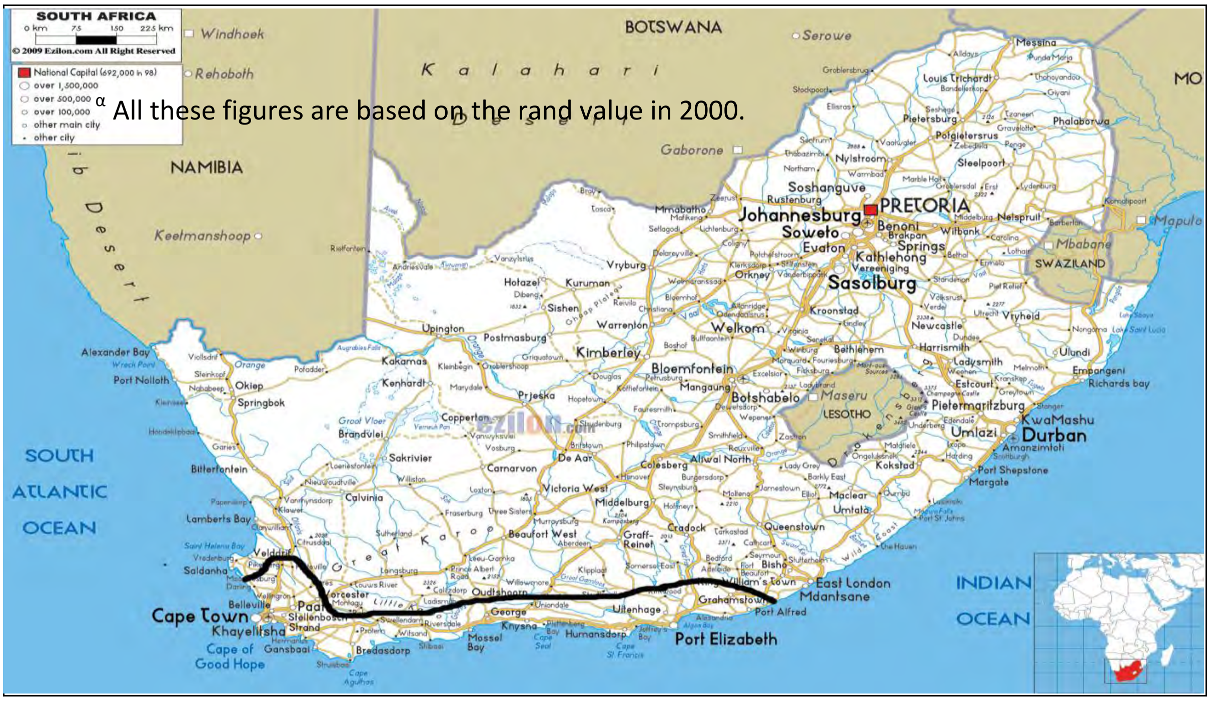
Spalding-Fecher et al (2002) estimate the health cost saving for ceiling interventions in South Africa is R 8.3 million/year (based on the 2000 rand value) and CO_2 emission reduction is 103 kilotons per year. This was based on the existing formal low-cost houses in South African urban areas of approximately 800,000 in 2000, of which the ceiling programme aimed to penetrate two thirds of that urban market. These figures look to be understated. They further state that the improvement in household energy savings resulting from ceilings is substantial. With the take-back (rebound) effect accounted for, ceilings provide an average of R438 per year per household in energy savings. Without the take-back effect, households save an average of R781 - a difference of R343 per year [α].

Whilst thousands of houses have been built in Cape Town during the last 17 years, over 450,000 people remain on the housing waiting list across the municipalities. Many of the houses built lack basic thermal efficiency installations such as ceilings or insulated windows. In the Western Cape alone, 40,000 low-cost houses lack ceilings. This has resulted in thousands of low-income households spending much of their limited funds on energy, while suffering a disproportionate health burden, exacerbating the energy poverty situation faced by these communities (Phillips, Silver & Rowswell, 2011).

Insulated ceilings are primarily considered an energy efficiency intervention. A wider understanding of their benefit to households is required in order to meet the challenge of the 40,000 RDP houses in the Western Cape lacking such thermal protection (Phillips, Silver & Rowswell, 2011).

The ceiling insulation problem is more acute in the Western Cape. Physical on-site investigations by Agrément were combined with computer simulations of the thermal performance of low-income houses. The results revealed that severe condensation is a significant problem in the coastal area of the Southern Cape, known as the Southern Cape Condensation Problem area (SCCP) (Agrément, 2002). The boundary runs from Malmesbury, close to the South-West Cape coast, inland through the Western Cape and into the Eastern Cape ending at Port Alfred (see Figure 2). As is evident on the map below, the boundary of the SCCP area runs south of the major mountain ranges in the Southern Cape and includes the area of the country that receives medium annual rainfall (between 250 mm and 500mm per year). It is thus a climatic phenomenon (Agrément, 2002). This problem area includes the town of Mamre, the survey area for this paper.

Figure 2: Southern Cape Condensation Problem Area



α All these figures are based on the rand value in 2000.

Source: http://www.ezilon.com/maps/africa/south-africa-road-maps.html

Intense condensation occurs when the moisture-laden air from outside enters the building and comes into contact with any surface that is cooler than the dew-point temperature of the air. Such a surface may be a window pane, window frame, badly insulated external wall, roof, or any other area where a thermal link occurs (Agrément, 2002). During the winter months, humidity is first noticed on the windows: when warm, moist air comes into contact with a cold window, the air temperature drops to a point where it can no longer hold the water vapour and condensation results. Condensation on the walls will lead to further condensation in the rest of the house if a home does not have the proper ventilation. Excess water vapour can permeate through walls and ceilings, causing wet insulation, heat loss through energy transfers, peeling paint, stained ceilings and walls, mould on walls and rot in woodwork. These all contribute to creating a breeding ground for insects such as termites and cockroaches. Too much indoor humidity can also lead to an increase in common indoor air pollutants, such as dust mites, bacteria, and viruses. Exposure to mould from high humidity levels may cause irritations of the throat and lungs and has been linked to worsening asthma symptoms, increased coughing, wheezing, nasal congestion, sore throat, sneezing, and rhinitis (EPA, 2013). Humidity thus directly affects the amount of allergens in the indoor environment.

Over the last ten years, in recognition of the SCCP, the National Government has provided a national housing subsidy for insulated ceilings in new RDP housing in the Western Cape. This acknowledges the need for increased thermal efficiency in the region and highlights the energy efficiency of this type of housing. The ceiling retrofit programme aims to address this issue by providing insulation and increasing the room temperature of houses, thereby reducing condensation. The housing subsidy ranges between R55,000 and R84,000 per house. The cost of installing a ceiling in a standard RDP house varies between R6,500 to R7,500, according to the national housing subsidy top-up available for the SCCP (SEED, 2011).

However, no state funding has been made available for the houses already built that lack ceilings and are now privately owned. This private ownership makes it difficult to fund any retrofitting work owing to the Municipal Funding Act, which means that new models of retrofit financing are required (Phillips, Silver & Rowswell, 2011). In other words, any future funds for retrofitting of ceilings will need to be provided by private donors and organisations.

2.8. Ceiling and other energy efficiency interventions

There has been a number of ceiling intervention and retrofit programmes around South Africa. This paper will review four of them; namely Mamre, Kuyasa, Cosmo City and Cato Manor.

2.8.1. Mamre

Mamre is a low-income community situated in the City of Cape Town Municipality, roughly 30km north of central Cape Town, close to the town of Atlantis (see Figure 3). Mamre was established as a village and mission station in 1808 by Moravian missionaries. It was at first known as Groene Kloof, after the Dutch East India Company post established there in 1701 and abandoned in 1791. It was subsequently renamed after the biblical Mamre (Genesis 13:18), a name said to mean "grazing land" (Dictionary of Southern African Place names, 2014). The RDP at Mamre took the form of a 400-house project, launched in 1997 (see Figure 4). In 2011, the population in Mamre was 9,048 (2011 Census) and the number of households was 2,226, all electrified. The average household size was 4.06 persons and 69.8% of the community households earned less than R6,400 a month. The City of Cape Town's Housing Department identified Mamre as a small RDP housing community, perfect for a pilot project for the ceiling retrofit programme in 2010 to address the SCCP discussed above. A ceiling retrofit is a process of builders going back to existing houses and installing ceilings between the roof and living space where none existed previously. A 5.4mm thick rhino board is used for the ceiling, with 50mm glass wool or polyester insulation (Phillips, Silver & Rowswell, 2011).

Figure 3: Map of Mamre

Source: Google Maps

Figure 4: Mamre Community

Source: Phillips, Silver & Rowswell, 2011

The Expanded Public Works Programme (EPWP) is part of the Government's selection of programmes that aims to provide temporary employment for unemployed citizens. The

Mamre Ceilings Project is a registered EPWP project that aimed to create jobs for the Mamre community (Phillips, Silver & Rowswell, 2011).

This project was developed to address the inefficient energy design of the houses, with the specific aim of retrofitting insulated ceilings in order to improve the quality of life of Mamre residents and reduce the required monthly expenditure on energy sources. Houses without ceilings or adequate thermal insulation are hotter in summer and colder in winter. Good insulation helps reduce the need for additional heating from fires/electric heaters and prevents damp and mould from forming, leading to associated health benefits. The house also becomes less vulnerable to wind, and less dust and fine particles are able to make their way into the house during Cape Town's hot and dry summers, providing further relief to household members suffering from asthma or other respiratory conditions (Phillips, Silver & Rowswell, 2011).

The project comprised a R1.9 million investment in the installation of insulated ceilings in Mamre. The retrofit project was funded by the Danish International Development Assistance (DANIDA) Urban Fund, through the program 'Promoting Resilience of At-Risk Communities in Climate Change'. The project took place during 2010 with around 240 insulated ceilings installed in Mamre RDP houses, out of a potential 400 RDP houses. The International Council for Local Environmental Initiatives (ICLEI) partnered with the City of Cape Town to assess the impact of the newly installed ceilings at a household and wider community level (Phillips, Silver & Rowswell, 2011).

Following the retrofitting project, an evaluation was conducted to analyse the impact of the insulated ceiling installations and provide a chance to reflect on the challenges, opportunities and issues associated with this type of intervention (Agrément, 2002). Results showed that houses without sufficient thermal efficiency will have a livelihood impact on families, communities and Government, including health and energy costs. Thus, understanding how retrofitting ceilings can provide a financial saving for cities that support both local communities and wider urban areas is important (Phillips, Silver & Rowswell, 2011).

Other retrofitting pilot projects have taken place within the City of Cape Town, the evaluation of which complements the aims of the Mamre project in seeking to widen the knowledge base for the City of Cape Town and thereby further consider, plan and fund retrofitting work on a larger scale (Phillips, Silver & Rowswell, 2011).

The project was in line with a number of objectives set out in the City of Cape Town Climate Action Plan. These objectives were: a city-wide reduction in electricity consumption of 10%, adapting to and building resilience to climate change impacts in low-income/vulnerable communities and local economic development in the energy sector (Phillips, Silver & Rowswell, 2011).

The Mamre ward councillors are the appointed representatives for the community and their insight and influence contributed greatly to the selection process for the ceiling retrofits. Once the community had been identified, the project team from the city worked with the ward councillors of the area to determine the criteria with which to identify beneficiaries on an equitable basis. To this end, preference was given to the more vulnerable groups within the community such as the elderly, unemployed and disabled, as well as to child-headed and single parent households. The ceilings were thus not randomly allocated. In addition, beneficiaries had to be the original owners of the RDP house and no tenant-occupied houses were retrofitted. Prior to the ceilings retrofit project, there had been another energy efficient intervention in the community – solar water geysers had been installed in a few of the houses. Residents who had benefitted from the solar water geyser intervention were excluded from the ceiling retrofit project. Community Liaison Officers (CLO) from the Housing Department subsequently undertook home visits within the community to identify the households that fulfilled the criteria. A total of 240 out of 400 households were selected to receive ceilings (Phillips, Silver & Rowswell, 2011).

Picture 3: Ceiling retrofitting in Mamre

Picture 4: Further ceiling retrofitting in Mamre

The Mamre project report was done in two stages. Stage 1 involved a survey of 50 households to develop a 'climate risk assessment' in August 2010. A follow-up survey of 50 households was concluded in January 2011, after retrofitting. Stage 2 involved a survey of 140 households with ceiling retrofits in August 2011 (Phillips, Silver & Rowswell, 2011). These survey results are further discussed in section 2.9.

2.8.2. Cosmo City

Cosmo City, 30km north-west of central Johannesburg, has long been envisioned as a sustainable human settlement. To date, the installation of ceiling retrofits, fluorescent lights and solar water heaters in 700 RDP houses in extension 2 of Cosmo City is one of the largest retrofit projects undertaken in South Africa. These were considered the most viable energy-related interventions. Isoboard was chosen for the ceiling and consists of an extruded polystyrene board, which acts as a combined ceiling and insulation material. It is easy to install, which was a benefit when it came to training up local labour. It also provided an attractive finish that is both water and fire resistant. The ceiling material and installation costs for each household amounted to R5,480, which included the Isoboard, cornices, brandering, electrical conduit, light boxes and fixative (SEED, 2011).

The entire process spanned just over 2 years, with project design and planning taking root in July 2008 through to implementation between April and September 2010. The first challenge involved the selection of households that would benefit from the project. A limited budget meant that only a few hundred out of the approximately 3,500 households in Cosmo City could be selected as beneficiaries. Through a close consultation process with the local Ward Councillor and Community Liaison Officers, it was decided that the oldest communities (by building years not resident ages) would be the primary beneficiaries (SEED, 2011).

Quantitative data logging was conducted to measure the impact of the intervention, involving capturing data over time using a machine to record readings. This monitoring involved continuously recording electricity usage in addition to indoor and outdoor temperatures in five houses with different orientations, room layout and usage patterns. This was conducted before and after installations of solar water heaters, lights and thermal insulated ceilings. The results are discussed in section 2.9.

2.8.3. Kuyasa project

Kuyasa is a low-income community in Cape Town. The Kuyasa report by Walsh, Wesselink & Janisch (2011) focuses on a particular area within Kuyasa, comprising 2,300 low-income RDP households. The Kuyasa Clean Development Mechanism (CDM) project was developed to address the inefficient design of the houses, with the particular aim of improving the quality of life of the Kuyasa residents and reducing the required monthly expenditure on energy sources (Walsh, Wesselink & Janisch, 2011).

The successful implementation of this project required finance, buy-in and support from many different parties, including the private sector, as well as national, provincial and local government. The project's main interventions were the installation of solar water heaters, thermal insulating ceilings, energy efficient lighting and improved wiring. Some houses also received 'hotboxes' (thermal insulation cooking devices), which help to reduce the cost of cooking. All households in Kuyasa are electrified, and pre-paid meters were installed in each home (Walsh, Wesselink & Janisch, 2011).

Two surveys were conducted within the community. The first survey was conducted before installation, canvassing 1,776 households (81% of the selected area). The second survey was conducted after the installation, canvassing 680 households (31% of the selected area). These surveys aimed to provide insight in the energy consumption patterns of the community as well as to determine the frequency of respiratory illness. The surveys provide very detailed information into the demographics, poverty levels, monthly expenditure on electricity and fuel as well as the type and frequency of respiratory illnesses experienced. The survey results were confirmed through informal interviews and focus group discussions and are analysed in section 2.9 (Walsh, Wesselink & Janisch, 2011).

2.8.4. Cato manor retrofit

Thirty low-cost houses in the historic township of Cato Manor in Durban received a 'green' upgrade. Each household received an energy efficient retrofit in the form of solar water heaters, insulated ceilings (made from Isoboard), efficient lighting, and heat insulation cookers. Qualitative data was drawn from pre- and post-implementation household surveys. The pre-installation survey took place in early November 2011, and the post-implementation survey was conducted in early March 2012, three months after completion. Quantitative data for the Cato Manor project was collected in the form of electricity usage patterns, temperature and humidity readings and the results are discussed in section 2.9 (Green Building Council of South Africa, 2012).

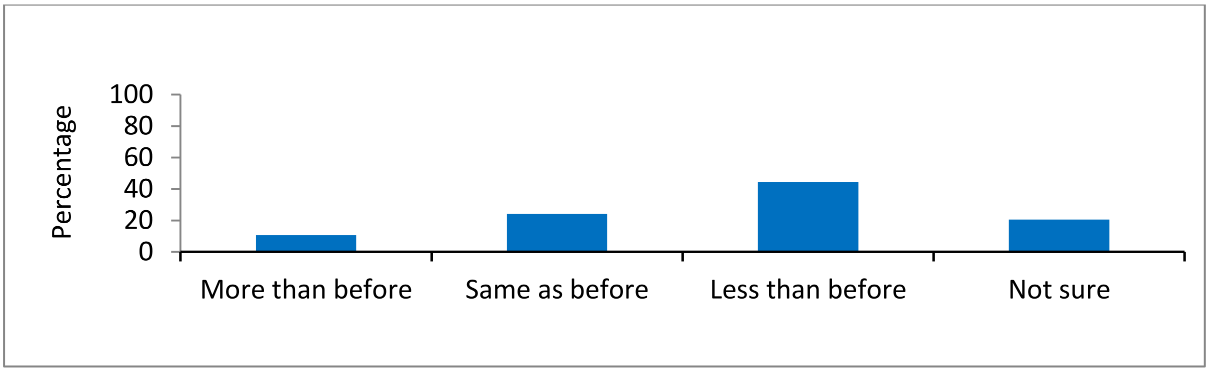
2.9. Ceiling and other energy efficiency intervention results

The initial results from the above projects suggest that improvements in a number of key themes have all been recorded, namely energy, health and livelihoods

2.9.1. Energy

For the Mamre project, thermal efficiency appears to have increased significantly with households requiring less energy to heat the space, thereby creating a range of new energy practices. These include households needing less energy to heat their homes, resulting in overall energy savings that are either used for heating the home for longer, redirected toward supressed demand from other electrical appliances or converted into financial savings (see Figure 5). Furthermore, the intervention has had a significant impact on the use of non-electrical heating sources, with reductions in potentially dangerous practices such as indoor fires. The Mamre results suggest that the insulated ceiling intervention has reduced the amount of electrical energy required to heat a house in 64% of households that had an opinion (Phillips, Silver & Rowswell, 2011). This supports the theory that ceilings increase thermal efficiency in low-income housing.

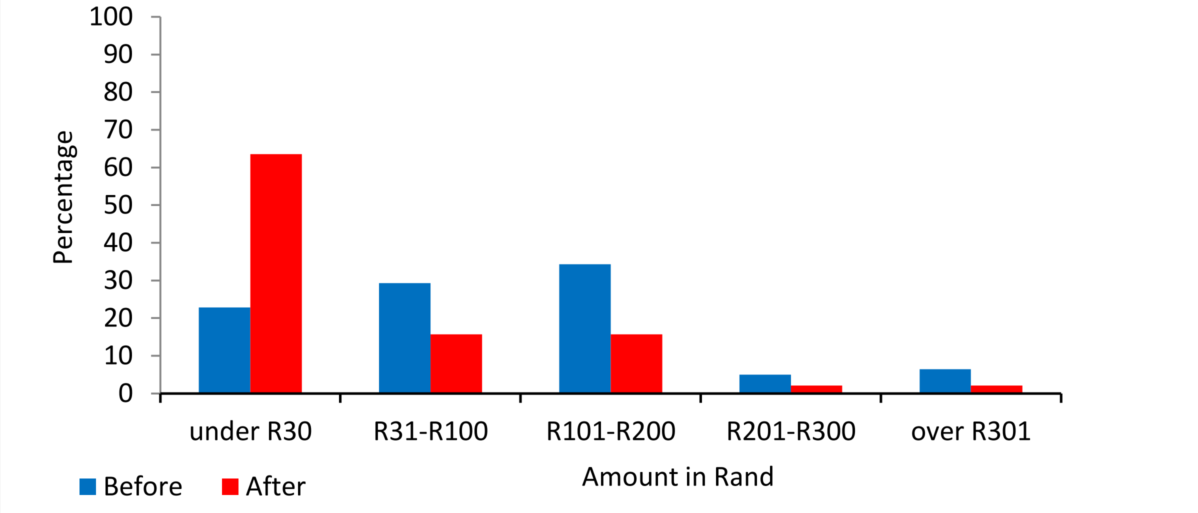
Figure 5: Fuel expenditure for heating before and after ceiling retrofits



Source: Phillips, Silver & Rowswell, 2011

For 44% of the surveyed Mamre households, the reduction in the amount of electricity required to heat the house has also meant a reduction in overall fuel costs for energy consumption. It should be noted that this is not a uniform response as some households claimed to spend the same amount on fuel as before the intervention and a minority claimed an increase in fuel expenditure (Phillips, Silver & Rowswell, 2011). This could be due to the substantial increases in electricity prices that have affected South Africa since 2010. The amount spent on energy before and after installation can be seen in Figure 6 below.

Figure 6: Monthly expenditure on energy before and after ceiling retrofits



Source: Phillips, Silver & Rowswell, 2011

Monitoring household energy usage at Cosmo City also demonstrated similar reductions in energy expenditure. It was projected through energy modelling that each household would save approximately R1,155 per year in electricity costs from the interventions, or a monthly average of R96 (SEED, 2011).

The Kuyasa project has had an impact on the financial stability of households, with a significant decrease in monthly electricity and fuel expenses within the higher usage brackets of R101-R200, R201-R300 and over R301 in energy expenditure per month and an increase in the lower usage brackets of under R30 and R31-R100. This is a vital reduction, particularly when many households have less than R100 in monthly disposable income. As a result, households have more money available to spend on basic necessities such as food and clothing. Energy modelling performed shows that the installation of ceilings in RDP homes could potentially result in an energy saving of 1,345kWh per year, or a 20% reduction in energy use for space heating. Kwh represents a kilowatt hour which is a unit of energy equal to 1,000 watt-hours and is the most common billing unit for energy delivered to consumers by electricity utilities. Here, energy is defined as power in watts over a given period of time. These modelling calculations were validated by physical measurements of indoor temperatures as well as surveys of energy use in homes with and without ceilings. If this energy was generated by electricity or paraffin, a saving (or at least an avoided cost) of R890 per year (at an electricity cost of R0.66 per kWh) or R1,570 per year (at R12 per litre of paraffin), would result per household, respectively (Walsh, Wesselink & Janisch, 2011).

The results in Table 1 were compiled by modelling software showing the benefits of different ceiling and insulation types. The model is based on a Kuyasa RDP home and was supplied by Sustainable Energy for Environment Development Programme (SEED, 2011). The improvement percentage from ceiling installations ranges from 43% to 71% in heating required per year in kWh, depending on the type of board and insulation used. Isotherm provides the best insulation material combined with the ceilings.

Table 1: Energy Improvements from the Kuyasa ceiling retrofit

Type of ceiling	Heating Required/yr (Kwh)	Improvement %
No Ceiling	2685	0
9mm Gypsum Ceiling	1505	43
9mm Gypsum Ceiling plus Sisalation	1216	54
25mm Isoboard Ceiling	785	70
9mm Gypsum Ceiling plus 50mm Isotherm	761	71

Source: SEED page 2, 2011

The Cato Mano project compared the energy patterns of two houses (an East and West facing house) over 5 months (May - September), showing that households can save up to 25% of their electricity bill. Total savings for the West House were 274Kwh and for the East house 277Kwh, for the 5 months from the ceiling installation (see Table 2). A saving of R223 per year per house from space heating is possible using an electricity rate of 81.5c/Kwh[θ], as a result of the insulated ceiling. If this were rolled out to the 3 million RDP houses it would equate to a saving of 822GWh (Gigawatt hours) of electricity and R 670 million saved in total (Green Building Council of South Africa, 2012).

Table 2: Improvements from ceilings in the Cato Mano project

Kilowatts per hour used per month for heating	Ceiling		No ceiling		Savings	
Month	West House	East House	West House	East House	West House	East House
May	50	50	96	96	46	46
June	78	79	148	149	70	71
July	78	79	153	155	75	76
August	60	61	110	111	50	50
September	51	52	85	86	34	34
Total kWh	317	320	591	597	274	277

Source: Green Building Council of South Africa, page 52, 2012

The minimal change in most of the electricity usage patterns following the interventions in Cato Manor could be due to the 'rebound effect' or the possibility that Durban does not get as cold as often as Cape Town or Johannesburg. When financial savings are realised, the 'spare' money is often used to purchase more electricity for other household needs.

[θ] Electricity tariffs are dependent on individual municipalities

2.9.2. Health

Overall, the insulated ceiling intervention can be considered to have significantly improved the climate resilience of the RDP houses in Mamre, by providing warmth and protection from the rain in the winter and acting to cool the houses during the summer. Significant health improvements have been recorded by households since the installation of the ceilings in both the summer and winter (Phillips, Silver & Rowswell, 2011).

The Cosmo City results were similar to the Mamre project, also showing an improvement in health following ceiling retrofits (SEED, 2011).

The most notable effects of the Kuyasa project have been on the overall health status of the community and an improvement in the residents' quality of life. 33% of the residents indicated that the Kuyasa project has made their life easier. This has been attributed to an improvement in health, a warmer and cleaner house, and a reduction in energy expenditure (Walsh, Wesselink & Janisch, 2011).

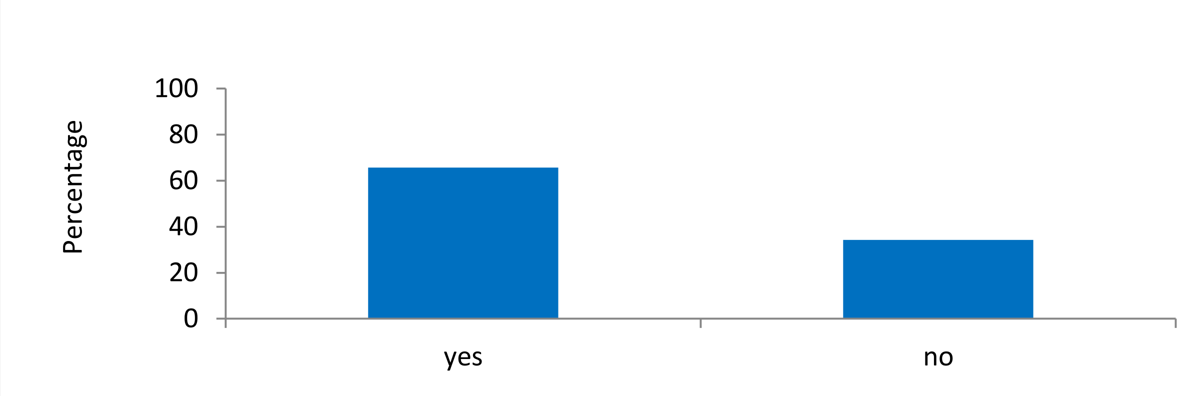
From the Mamre results, households previously experiencing adverse impacts from wind and rain have dropped from 66% to 9% and from 64% to 2% respectively, showing the improvements in the overall climate resilience of RDP houses when insulated ceilings are installed. Household damp has a range of serious health implications. Whilst there has been a 45% reduction in households experiencing damp due to the insulated ceiling retrofit, it still affects 36% of households with ceilings. One explanation for this is the failure to plaster all the walls of the RDP house. Although damp is prevented from entering the house via the roof, it still enters through the walls, floors, doors and windows - providing a serious problem to Mamre households (Phillips, Silver & Rowswell, 2011). This is an important finding to reflect on in further studies.

81% of households in the Kuyasa project indicated that there had been a decrease in the frequency of illness due to the interventions. Households experiencing illnesses twice or more a year dropped significantly from 79% to 26%. Close to half (43%) of the respondents attributed their improved health to the ceilings or the warmth of the house. Positive health effects also resulted from less dust and sand in the house. 49% of residents in the follow-up survey at Kuyasa indicated that the house was warmer because of the ceiling (Walsh, Wesselink & Janisch, 2011).

Furthermore, there is evidence from the household surveys in Cato Manor to suggest that both respiratory illnesses and waterborne diseases have been reduced by up to 20% due to ceiling retrofits.

Phillips, Silver & Rowswell (2011) have shown that 67% of the Mamre households noticed a difference in family health since the ceiling installation. This is an encouraging result when considering the low cost of the intervention (see Figure 7).

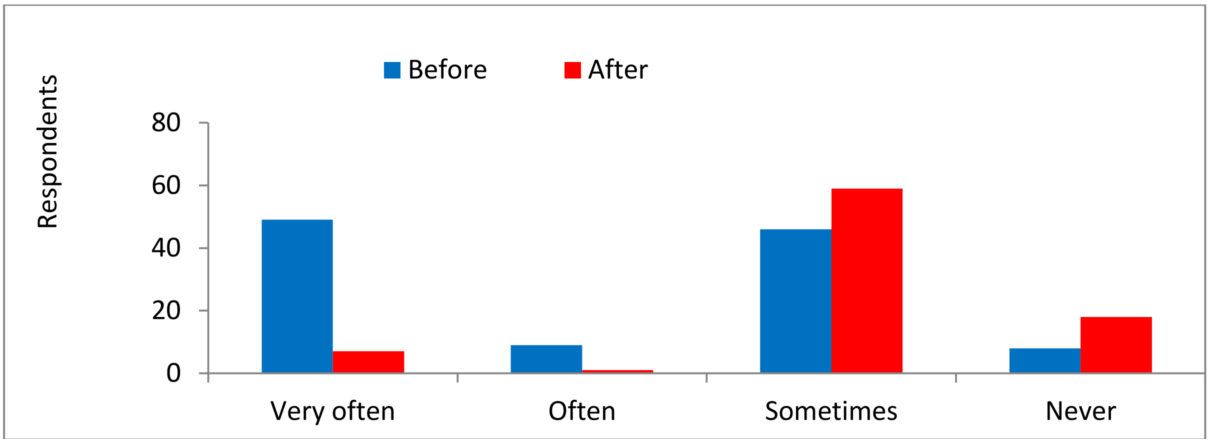
Figure 7: Family health improvement since the ceiling installation



Source: Phillips, Silver & Rowswell, 2011

Phillips, Silver & Rowswell's (2011) Mamre survey and interview process both indicate that TB has been reduced over the period in which the ceilings have been installed. Responding households have recorded a reduction in the frequency of TB, with the data showing households suffering from TB 'very often' or 'often', reducing from 31 cases to 5 cases - showing the significant impact of the intervention. In addition, their research has shown a dramatic reduction in the frequency of colds and influenza in households that received insulated ceilings. Households recorded a reduction of illnesses occurring 'very often' from 49 to 7 households. The emerging evaluation data further suggests that the ceilings have contributed to a substantial reduction in the frequency of asthma and other breathing difficulties, with households recording a frequency of 'very often', reducing from 24 to 6 households (see Figure 8). The results show that 86% of households are much happier, indicating the importance of improving housing conditions of low-income communities. Other factors that could explain this improved happiness were suggested by residents included aesthetic reasons and working alongside a pro-active municipality (Phillips, Silver & Rowswell, 2011).

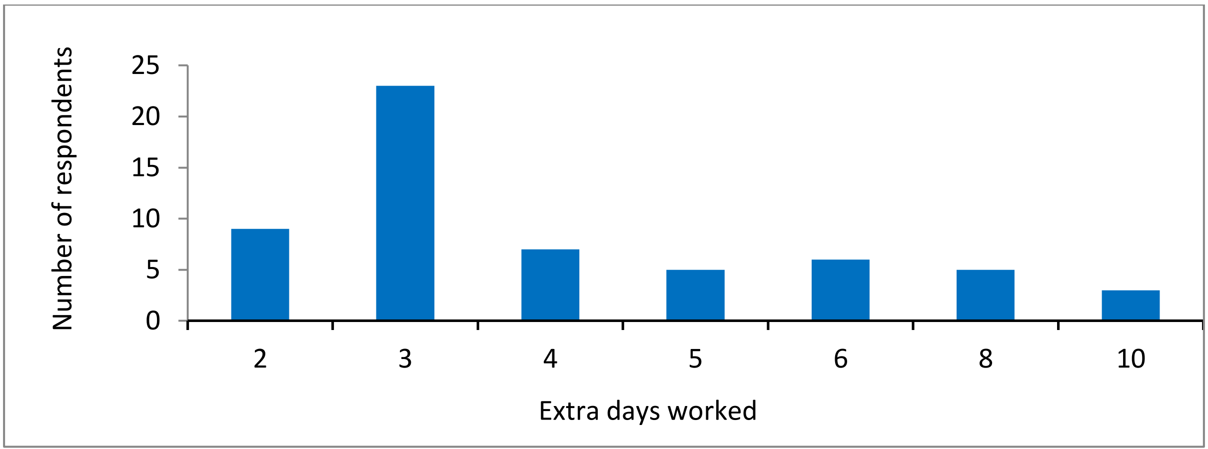
Figure 8: Frequency of illnesses in household (per annum): Cold and influenza before and after ceiling installation.



Source: Phillips, Silver & Rowswell, 2011

One method of calculating the health savings can be through considering the number of work days saved through ceiling interventions. According to Phillips, Silver & Rowswell's (2011) calculations, an extra R36,900 (or R154 per household) per year has been generated for the retrofitted houses in Mamre by the residents taking fewer sick days due to health improvements over the year (see Figure 9). The Mamre research shows that in total, 193 extra days of school have been attended by children and young people in the Mamre retrofitted homes (240 houses) over the last year, due to the improvements in community health that the ceilings have offered.

Figure 9: Improved health in ceiling retrofit households in terms of reduced sick days off work



Source: Phillips, Silver & Rowswell, 2011

Around 20% of respondent Mamre households reported a saving of medical costs resulting from improved household health. The highest proportion of respondents purported to save around R250 per annum. The research has recorded a total of R6,070 saved for all the households (R25 per household) in medical costs over the last year which can therefore be directed to other expenses within the household (Phillips, Silver & Rowswell, 2011).

2.9.3. Job creation

The Mamre project implementation has provided 18 short-term employment posts and 8 permanent posts with training opportunities for the members of the community, many of whom experience short and long-term periods of unemployment. Local community members were employed to assist with the installation of the ceilings, carry out surveys and raise awareness among the community. The consistent and inclusive engagement with the community throughout the project nurtured a sense of pride and ownership within the community and ensured that the project ran smoothly on the ground (Phillips, Silver & Rowswell, 2011).

Additionally, one of the Kuyasa project's key aims was to support local job creation and skills development. Members of the community were trained and employed through the project to install the various technologies, resulting in over 65,000 days of labour in total (Walsh, Wesselink & Janisch, 2011).

2.9.4. Evaluation and analysis of previous interventions

A critique of the papers discussed above is the following:

- They do not measure the combined temperature, humidity and CO_2 levels within the houses, thus showing no detailed indication of the impact of ceilings or other interventions on these important health indicators.
- The CBA measures that were completed leave out a number of externalities such as greenhouse gases.
- The amount saved by households with retrofitted ceilings does not reflect the entire savings in health costs. In South Africa, the government provides subsidised clinics and hospitals to low-income communities.
- The take-back or rebound effect of the energy savings from the interventions was not adequately accounted for. As discussed above, the take-back effect linked to energy is quite substantial in developing countries.
- They fail to take into account the overall poor building quality of the RDP houses, including the walls, floors, doors and windows. These all influence the energy efficiency and health of households.

This paper will address these critiques as follows:

- To fill the gap by measuring CO_2, humidity and temperature within retrofitted ceiling households.
- To add more weight and evidence behind the CBA of ceiling interventions by including a large number of social externalities.
- To take into account the health savings from both the household and government's perspective.
- To eliminate the energy usage related take-back effect by making a cross-sectional comparison between ceiling and non-ceiling houses as opposed to a time-sectional comparison of ceiling houses. The take-back effect relates to increased expenditure on electricity for non-heating related appliances over time, as savings are made on heating related appliances through insulated ceilings. Since this also improves the quality of life, a good case can be made for excluding it on basic principles.
- As it is very hard to account for the building quality, given the lack of samples of well-built RDP houses with ceilings, this critique will not be addressed.

3. Methodology

3.1. Research

Evaluation research was undertaken by the City of Cape Town in the Mamre area in 2010, before and after the installation of the ceilings. The city continues to engage with the community in order to explore the issues and impacts surrounding the intervention.

This thesis is a continuation of the on-going research process monitoring the impact of the insulated ceilings in Mamre. From the literature review, it can be concluded that ceilings are a vital intervention in dealing with health and energy poverty.

Firstly, this project included quantitative data that provided a numerical base for the evaluation. This evaluation measured a number of key issues: including energy and health savings as well as environmental and lifestyle impacts. It is important to continue this quantitative monitoring to provide a long-term picture of the intervention. Secondly, the research included an element of qualitative data that has allowed for the research to move beyond mere numbers and explore the issues with residents in greater depth. This aspect of the research is important as it provides a wider picture of the interventions and allows for a better understanding of people's views and impressions of the ceiling project. Finally, the data was incorporated into a CBA for this intervention.

The qualitative and quantitative surveys encompassed 60 low-cost houses in Mamre, 30 ceiling retrofit houses (CRH) and 30 non-ceiling houses (NCH). This study compared the impact of the ceiling installations on energy, health, environment and lifestyles by observing these households. With the comparison being conducted at a particular point in time, the rebound effect for energy usage has been nullified as the comparison is across two types of houses and not within each house.

A short, pilot survey project was initiated in Mamre in early August 2013 to get a feel for the type of questions that should be asked and what works and what does not work in the specific situation. It was a study focusing on 4 houses in the area (2 CRHs and 2 NCHs). It was then upgraded to the full 60-house study after reviewing the pilot survey results and making a few amendments to the questionnaire.

Following this, the research conducted was characterised by a two-part process, which is outlined below:

Part one:

- A qualitative Survey involving 30 CRHs and 30 NCHs.

Part two:

- A quantitative data collection involving the same 30 CRHs and 30 NCHs.

The households used in the survey were randomly selected from the 240 CRHs and 160 NCHs in Mamre. Rochelle Windvogel and Peter Adonis, local research assistants, went street by street through Mamre randomly choosing CRHs and NCHs that were willing to participate in this study, until they accumulated 30 houses each. The surveys and data collection were completed by these two assistants under supervision. The assistants were mixing and matching the types of houses surveyed each day, as in each street there were a mixture of CRHs and NCHs. This meant that on each given day they would collect data from both CRHs and NCHs.

The qualitative surveys (see Appendix 1) focused on asking pertinent questions around the energy consumption, health impacts and lifestyle patterns of households with and without ceilings. Each household was asked a series of 20 questions by the assistants. In order to deal with subjectivity bias from the assistants, each question in the survey was reviewed prior to the project, in detail over a 3-hour period, discussing what it was aiming to gather, emphasising repeatedly that it needed to be objective and that they must not push for answers they want.

The other vital topic in the surveys was the TB question. A number of respondents are suffering from TB in the CRH sample and comparably more in the NCH sample. To incorporate this, a question about clinic/hospital visits per person excluding TB and including TB was created as TB may have been contracted prior to the installation of the ceilings and would thus be hard to measure as an influencing factor.

After the final survey was administered, it emerged that two questions were too narrow in their formulation - an energy question where people were often stating R300 or more spent a month on energy and a health question where people ticked 5 or more times to visit a clinic/hospital. With so many residents ticking these boxes, the scope of these two questions needed to be enlarged. The assistants returned to re-ask these two questions, requesting a specific amount of expenditure on energy per month and a specific number of times visiting the clinic/hospitals.

In the quantitative approach, the assistants measured the temperature, humidity, carbon monoxide (CO) and carbon dioxide (CO_2) levels in each household using a machine called a Fluke 975 (see Appendix 4). This was measured twice for each of the 60 houses, using one machine. The first reading was taken between 7am and 11am and the second reading was taken between 7pm and 9pm in each house. This collection of data was completed during the cold, wet winter period of August and September 2013. The final sample size is thus 30 CRHs and 30 NCHs, with two quantitative data sets in the morning and evening and one qualitative data set each. These data sets were then compared across the two types of houses and to previous studies conducted.

The research team conducted interviews at 30 CRHs and 30 NCHs over August and September 2013. They had a few setbacks with the quantitative study as they had to repeatedly return to houses with the fluke machine where respondents were not available or working. They thus asked for an extended time slot from 7am-9am to 7am-11am in order to get all the testing of the houses completed. At the time of the quantitative study, the weather was unusually cold and wet; the average low temperature was 8°C and the average high temperature was 18°C in Cape Town in August 2013. The average daily rainfall was 6.4 millimetres with a high of 76 millimetres in August 2013 (Accuweather, 2014). The assistants completed all the surveys and data measurements in September 2013 and completed the 2 extra follow-up qualitative survey questions in early November 2013. The data was then entered into an Excel spreadsheet.

Some concerns with the measurements taken included the time of the readings and the conditions at each house. When you are taking a spot reading, small changes can affect the CO, CO_2 and humidity levels. For example, doors being left open or a time lag in taking the reading, which could increase the CO_2 levels since people breathe and talk through the surveys. The assistants were asked to take readings within the first 10 minutes with the doors closed in order to keep the results similar. A number of interviews were supervised to ensure that the assistants were following the correct procedure and process.

A feedback loop to measure validity of the surveys was created by capturing the contact details of the residents. Each household signed a consent form for this work and a University of Cape Town ethics clearance was obtained for the research.

3.2. Limitations, concerns and key assumptions

1. Each household did not have the exact same number of residents. On average, houses with more people tend to spend more money on energy than houses with fewer people. The energy spend was therefore averaged out over the sample of 60 houses.

2. There is no extreme bias in the way the samples were selected.

3. The ceilings installed are identical across the sample and have not been altered by the occupants.

4. Due to time and cost constraints, the sample size is fairly small.

5. There is a risk of the questionnaire responses being influenced by other factors such as education, family history, eating behaviours and/or lifestyles (such as drinking or smoking) that have not been accounted for.

6. There may be other house construction issues leading to a loss of energy and increased sickness in the houses which have not been accounted for in this study. These include: dampness, poor quality blocks, gaps in the door and window frames, poor roofing, plastering and flooring. However, due to the uniformity of the poor quality housing across the sample, the results of this ceiling intervention study are unaffected.

7. The data may have been influenced by the time it was taken, which varied between 7-11am and 7-9pm as well as by the different dates that it was collected on. For example, some days may have been colder, wetter or more humid than others.

8. Regarding the survey, the biggest concerns were with resident's interpretation of the questions, subjectivity of the assistants and the residents understanding of the questions.

9. Although TB is prevalent in the residents, determining whether it is contracted before or after the ceiling retrofitting is difficult to ascertain.

4. Results and discussion

The research included travelling regularly to Mamre to visit the households and discuss progress with Rochelle Windvogel and Peter Adonis, the research assistants. The research assistants were recommended by the City of Cape Town and had past experience in survey-based research. The assistants were thus confident and skilled in this form of research. They are both residents of Mamre, active members in the community and speak fluent Afrikaans, which lent them credence in the surveys.

A first impression of Mamre is that of a sleepy town waiting for a better life. It had great beginnings with the Moravian church involvement and its productive mill. By mid-1987, the rebuilding of the roads, electrification of the town and establishment of a small-scale rented housing scheme (short-term renting for the duration of housing renovation) was under way. However, the town has fallen on hard times lately with little work or opportunities currently available to its residents. A large number of residents travel to Atlantis daily for work.

One of the feedback loops created to verify the data was a call-back to some of the households surveyed to see if they were interviewed and that the answers they stated were factually correct. Eight houses were verified; it was found that they were all interviewed correctly and the answers and type of house (CRH vs NCH) were correct.

4.1. Quantitative Results

On the CO measurement, the fluke machine measured 50 houses with 0 parts per million (ppm) and only 10 houses having just over 0ppm, out of a CO calibration of 0 - 500ppm. The ceilings thus had little impact on CO across the sample. As it represented an insignificant contribution to the air composition in both types of houses, including it in the data was not merited.

Tables 3 - 6 highlight the data results from the fluke machine readings. The temperature reading is in degrees Celsius (°C), the humidity reading is non-condensing relative humidity as a percentage (this measures the current absolute humidity, relative to the maximum for that temperature) and the carbon dioxide (CO_2) reading is in ppm. The minimum column shows the minimum readings, the maximum column shows the maximum readings and the average column shows the average readings across the 60 households. Lastly, the live column is the instantaneous reading taken as soon as the machine is switched on, averaged across the 60 households. The first three lines show the results taken between 7am and 11am and the second three lines between 7pm and 9pm. Table 3 indicates the readings for the CRHs, Table 4 for the NCHs, Table 5 displays the difference between the CRH and NCH results and Table 6 displays the percentage difference between the CRH and NCH results.

Table 3: CRH temperature, CO_2 and humidity results

7am-11am	minimum	maximum	average	live
Temperature	15.7	16.3	16.2	16.5
Humidity	70.4	73.1	71.6	71.4
CO2	609.1	762.1	743.2	823.0
7pm -9pm	minimum	maximum	average	Live
Temperature	15.2	16.7	16.6	17.5
Humidity	74.8	79.1	76.3	74.0
CO2	556.2	787.9	743.8	803.6

Table 4: NCH temperature, CO_2 and humidity results

7-11am	minimum	maximum	average	live
Temperature	14.3	14.7	14.5	14.7
Humidity	69.0	71.1	69.8	69.5
CO2	584.4	672.6	648.3	687.9
7-9pm	minimum	maximum	average	Live
Temperature	13.8	15.1	14.7	15.4
Humidity	70.8	75.3	72.4	70.5
CO2	593.7	762.0	713.9	769.7

Table 5: Differences between CRH and NCH results (CRH-NCH)

7-11am	minimum	maximum	average	live
Temperature	1.4	1.7	1.6	1.8
Humidity	1.4	1.9	1.7	1.9
CO2	24.7	89.4	95.0	135.1
7-9pm	minimum	maximum	average	Live
Temperature	1.4	1.7	1.8	2.0
Humidity	4.1	3.8	3.9	3.5
CO2	37.5	25.9	29.9	34.0

Table 6: Percentage difference between CRH and NCH (CRH-NCH)/ [(CRH+NCH)/2]

7am-11am	minimum	maximum	average	Live
Temperature	9.4%	10.7%	10.7%	11.3%
Humidity	2.0%	2.7%	2.5%	2.7%
CO2	4.1%	12.5%	13.6%	17.9%
7pm-9pm	minimum	maximum	average	Live
Temperature	9.9%	10.5%	11.8%	12.4%
Humidity	5.6%	4.9%	5.2%	4.8%
CO2	6.5%	3.3%	4.1%	4.3%

4.1.1. Temperature

Reviewing the results above, the temperature differences are clear. During the sample period, the average outdoor air temperature was 14.9°C in the morning and 13.8°C in the evening. The average temperature for the CRHs was 16.2°C in the morning and 16.6°C in the evening. The average temperature for the NCHs was 14.5°C in the morning and 14.7°C in the evening. The differences between the average CRH and NCH temperatures are 1.6°C and 1.8°C in the morning and evening respectively. CRHs therefore have warmer temperatures than NCHs during cold periods.

The percentages in Table 6 were calculated by taking the average difference between the CRHs and NCHs divided by the average of the CRH and NCH measurements combined. The results show that the percentage difference in temperature between CRHs and NCHs was 10.7% and 11.8% in the morning and evening respectively. It can thus be concluded that ceilings add an insulating factor by both warming the air faster and reducing the loss of heat through convection. This concurs with previous studies (Mamre, 2011), which suggest that the main impact of the insulated ceiling is to keep the house warm. One resident explained, "It is much better now and not so cold in the house." It should be noted that, even with this improvement, both CRHs and NCHs are approximately 2°C-4°C below the required minimum health standards according to the UN, which state that the space heating minimum daytime indoor air temperature is 18°C (UN Habitat, 2012).

4.1.2. CO_2

The results from the CO_2 and humidity readings appear to be counterintuitive. On average, the CO_2 levels are higher in the CRHs, both in the morning and evening. The differences are fairly substantial. The CO_2 average percentage difference was 13.6% in the morning and 4.1% in the evening, comparing CRHs to the NCHs. The average CO_2 was 743 ppm in the morning and afternoon for the CRHs and 648ppm and 713ppm for the NCHs in the morning and afternoon respectively. The difference between the CRHs and NCHs was 95ppm and 29.9ppm for the morning and afternoon respectively.

With the readings of CO_2 well below the harmful level of 1000ppm, it can be concluded that the CO_2 level in Mamre RDP houses is not dangerous. This lower-than-expected CO_2 level could be attributed to the electrification of the RDP houses, reducing the demand for other forms of fuel to cook and heat the house with. The abundant use of fuels such as wood, biomass, paraffin or gas would increase the CO_2 levels dramatically.

4.1.3. Humidity

The humidity levels present unexpected results too, with slightly higher average levels in the CRHs -the percentage differences were 2.5% in the mornings and 5.2% in the evenings, compared to the NCHs. Ideal indoor humidity levels should be around 45%. Anything less than 30% is considered too dry and anything over 60% is considered too wet (EPA, 2013). Outdoor relative humidity in Cape Town during August 2013 ranged from 54% to 97% (Weatherspark, 2014). The results above indicate extreme levels of indoor humidity, with NCHs averaging between 69.8% and 72.4% and CRHs averaging between 71.6% and 76.3% for the morning and evening respectively. Despite the aim of the ceiling retrofit programme to address the humidity issue by providing insulation it has not achieved this.

Damp problems are one of the most frequent problems encountered in the Mamre homes during the wet winter months. A good reason explaining these results could be that these insulated ceilings trap the air inside a house creating less space for ventilation. With a high roof and no ceiling there is more available air, which lends itself to lower levels of relative humidity (and lower levels of CO_2 ppm). With poor ventilation through the building, a ceiling acts like a lid trapping the air within the house and creating higher humidity (and CO_2) levels. Another reason could be that with higher temperatures in the CRHs, more water vapour can be stored in the air and less condensation occurs, thus resulting in slightly higher humidity levels.

More suitable methods to reduce humidity are to adequately ventilate and insulate a house. Ventilation can be achieved through additional air bricks allowing air to flow through the house. To prevent condensation, insulation can be added to cold surfaces such as windows, piping, exterior walls, roofs, doors or floors (Healthline, 2012). Damp proofing in construction is a type of waterproofing applied to the building foundation walls to prevent moisture from passing through the walls. A plastic layer called a damp proof course (DPC) is conventionally put into the walls of houses to prevent damp from seeping into the floors and internal spaces. The high humidity levels that were tested in CRHs and NCHs could be explained by a combination of absent DPC layers, insufficient air bricks and poor insulation. This is an important finding highlighting the need to address energy efficiency with a broad construction outlook.

In summary, although temperatures are higher in the CRHs, ceilings fail to remove the issues of humidity or to lower CO_2 levels, which are linked to poor workmanship, poor design and poor materials in the construction of RDP houses. Other studies on ceilings have not covered these findings.

4.2. Qualitative Results

The qualitative survey results from the 60 houses surveyed in Mamre are represented in the tables below. The first two columns (CRH and NCH) show the number of households, whereas the third and fourth columns (CRH % and NCH %) show the percentage of households.

4.2.1. Residential numbers

To get an idea of the residential numbers, the question posed to the residents was: "*How many people stay in your household?*" The results in Table 7 were averaged out over the 30 houses of each type.

Table 7: Residential numbers

Residential numbers	CRH	NCH
Average number of people living in a house	4.4	4.9

On the number of people per household, the NCHs and CRHs are quite similar with 4.9 people per household for the NCHs and 4.4 for the CRHs. This is comparable to the 2011 Mamre census with 4.1 people per household. In total, the NCHs had 7 residents over the age of 60, whilst the CRHs had 4. The NCHs had 64 residents and the CRHs had 30 residents under the age of 18.

4.2.2. Cooking methods

To uncover the cooking methods used, the question was asked "*What do you use to cook with day-to-day*?" The results are shown in Table 8.

Table 8: Cooking methods

Cooking methods	CRH	NCH	CRH %	NCH %
Electricity	30	22	100%	$73.\dot{3}$%
Electricity and firewood combination	0	7	0%	$23.\dot{3}$%
Electricity and LP gas combination	0	1	0%	$3.\dot{3}$%
LP Gas	0	0	0%	0%
Paraffin	0	0	0%	0%
Coal	0	0	0%	0%
Firewood	0	0	0%	0%

All the houses sampled were electrified. Regarding cooking, more households tend to use electricity in the CRHs (100% of the CRHs versus 73.$\dot{3}$% in the NCHs), with 23.$\dot{3}$% of the NCHs using firewood (normally used outside) to save money. None of the CRH residents use firewood or gas to cook with, whilst in the NCHs only 3.$\dot{3}$% use LP Gas and electricity. None of the houses use LP Gas, Paraffin, coal or firewood on its own to cook with. In the 2011 Mamre census, 96.6% of residents used electricity for cooking, 0.4% firewood and 2.4% gas with 0.5% using other forms.

A follow-on question was: "*How often is this fuel used to cook with in winter per day*?" The results are shown in Table 9.

Table 9: Cooking frequency

Cooking frequency	CRH	NCH	CRH %	NCH %
Electricity 5 or more times	22	18	73%	60%
Electricity 2 to 5 times	6	10	20%	33%
Electricity once a day	2	2	7%	7%
Firewood 5 times a day	1	4	3%	13%
Firewood 2 to 5 times a day	0	1	0%	3%
Firewood once a day	0	1	0%	3%
LP Gas once a week	0	1	0%	3%

These results clearly indicate that electricity is more frequently used to cook with in the CRHs and less frequently in the NCHs, with firewood used in 13% of the NCHs 5 times a day. The cooking method results highlight the reliance on electricity in cooking. The use of firewood or LP gas is infrequent or used outside, limiting harmful gases to the outdoors.

The following question in the survey was on the common problems with each type of fuel, shown in Table 10.

Table 10: Problems with the type of fuel (Electricity/Firewood/Paraffin)

Problems with the type of fuel	CRH	NCH	CRH %	NCH %
Expensive	27	26	90%	87%
It smells bad	0	1	0%	3%
It smells bad and expensive	3	0	10%	0%
Coughing and it smells bad	0	2	0%	7%
Coughing, it smells bad and expensive	0	1	0%	3%
Explosions	0	0	0%	0%
Children drink it	0	0	0%	0%

A common problem with the fuel choice is that it is expensive. This is confirmed by 90% and 87% of the CRHs and NCHs respectively.

4.2.3. Warmth

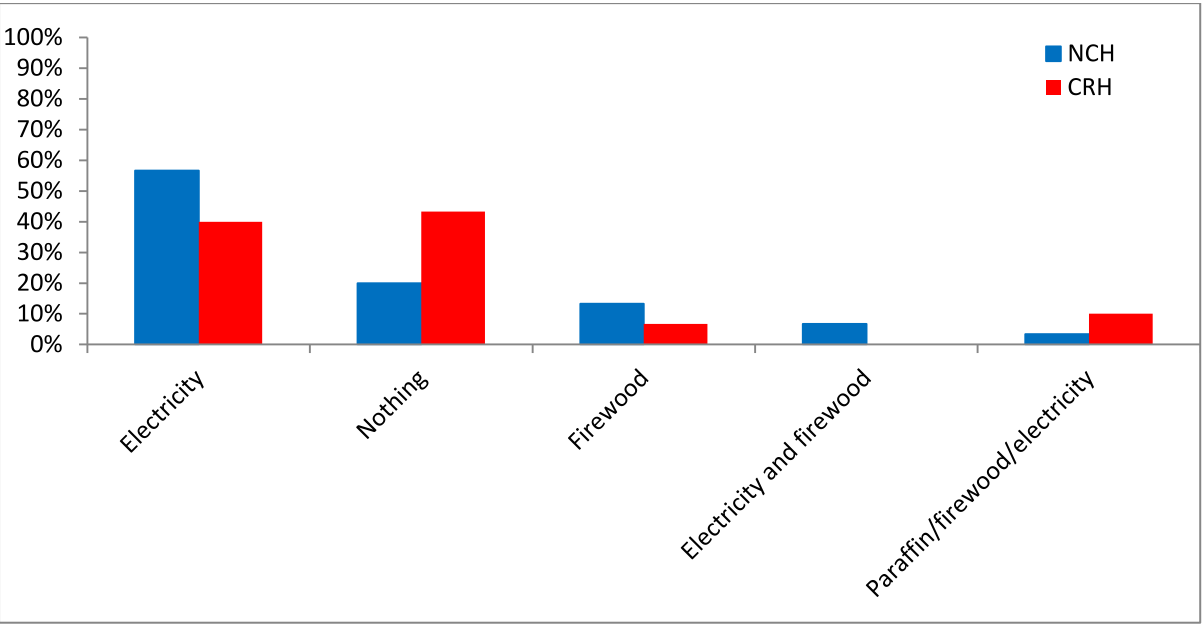
On the question of warmth, the residents were asked: "*What do you use to warm the house with day to day?*" The results are shown in Table 11.

Table 11: Warming the house

Warming the house	CRH	NCH	CRH %	NCH %
Electricity	12	17	40%	57%
Firewood	2	4	7%	13%
Electricity and firewood combination	0	2	0%	7%
Paraffin/firewood/electricity combination	3	1	10%	3%
Nothing	13	6	43%	20%
LP Gas	0	0	0%	0%
Coal	0	0	0%	0%
Paraffin	0	0	0%	0%

The findings for what residents used to warm their houses indicate that 43% of the CRHs use nothing for warmth, compared to 20% in the NCHs. 57% use electricity for warmth in the NCHs compared to 40% in the CRHs. 13% of the NCHs use firewood for warmth compared to 7% for the CRHs (see Figure 10). This is a significant difference showcasing the temperature differentials discussed above and the residents' tendency to spend more on heating in NCHs. A much larger percentage of CRHs, 43%, use nothing to warm the house highlighting the warmer indoor temperatures. For coal, LP Gas and Paraffin on its own, the usage is zero across the sample. This is not in accordance with the 2011 census, where total Mamre town usage of electricity to warm up the house was recorded at 83.9%, with 6.8% using firewood, 1.1% using gas, 7.5% using nothing and 0.6% using various other forms (Western Cape Government, 2011).

Figure 10: Warming methods in households during winter



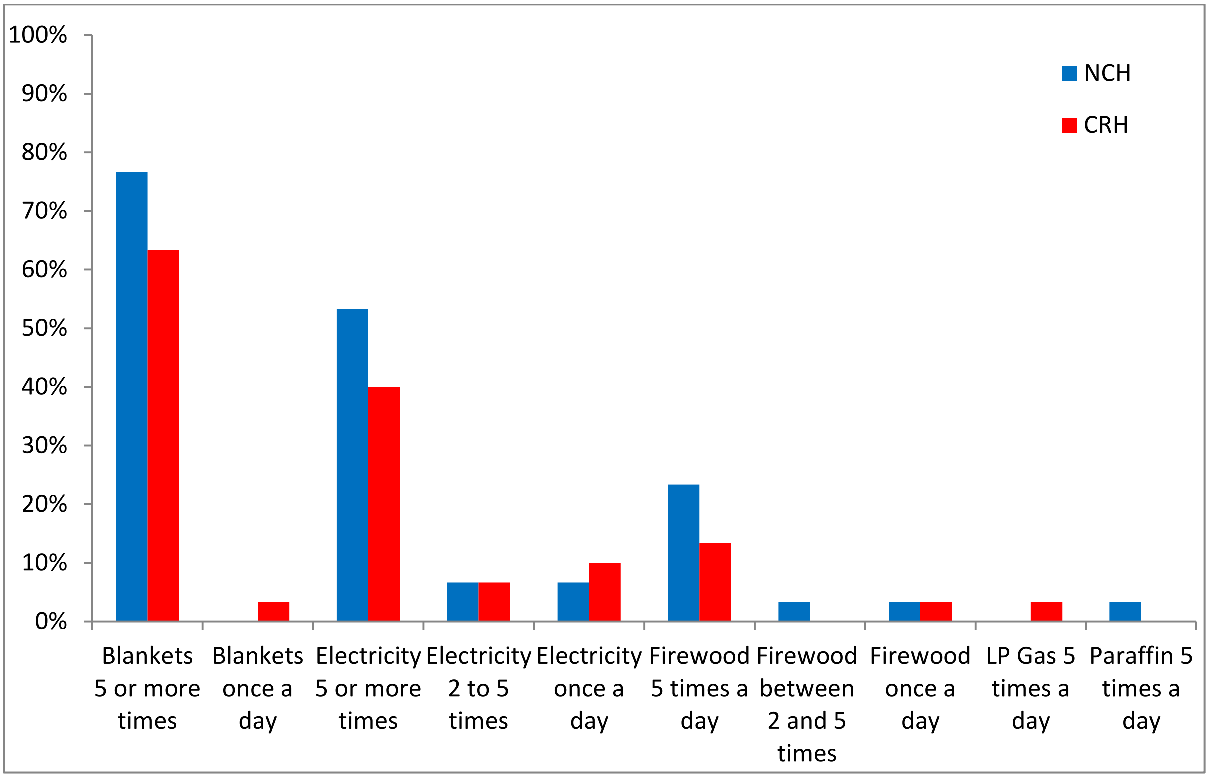
The next question was: *"How often is this warming method used to warm up the house in winter per day?"* The results are shown in Table 12.

Table 12: Frequency of warming methods

Frequency of warming methods	CRH	NCH	CRH %	NCH %
Blankets 5 or more times	19	23	63%	77%
Blankets once a day	1	0	3%	0%
Electricity 5 or more times	12	16	40%	53%
Electricity 2 to 5 times	2	2	7%	7%
Electricity once a day	3	2	10%	7%
Firewood 5 times a day	4	7	13%	23%
Firewood between 2 and 5 times	0	1	0%	3%
Firewood once a day	1	1	3%	3%
LP Gas 5 times a day	1	0	3%	0%
Paraffin 5 times a day	0	1	0%	3%

In the survey results for the number of times per day each method was used for warmth, again the NCHs come out as the colder household with 77% of the houses using blankets 5 times a day, compared to 63% in the CRHs. Firewood was used for warmth up to 5 times a day by 23% of the NCHs versus 13% of the CRHs and electricity was used for warmth 5 times a day by 53% of the NCHs versus 40% of the CRHs. Electricity usage 5 times a day is in reference to heaters, hot water bottles and warm liquids (see Figure 11).

Figure 11: Frequency of warming method to warm up the house in winter per day



4.2.4. Energy Expenditure

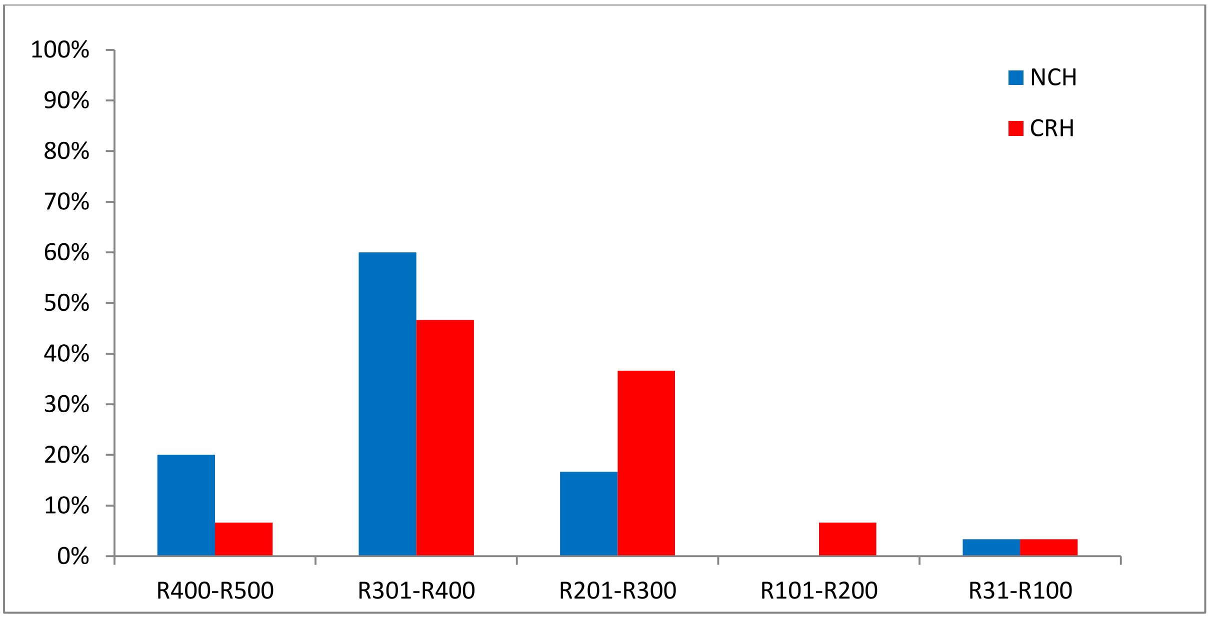
The question on energy expenditure was: *"How much do you spend on average for fuel for cooking and heating per month during summer and winter?"* The results from the survey regarding energy expenditure per month are found in Table 13 below:

Table 13: Monthly expenditure

Monthly expenditure	CRH	NCH	CRH %	NCH %
Winter				
R400-R500	2	6	7%	20%
R301-R400	14	18	47%	60%
R201-R300	11	5	37%	17%
R101-R200	2	0	7%	0%
R31-R100	1	1	3%	3%
Summer				
R201-R300	18	22	60%	$73.\dot{3}\%$
R101-R200	10	7	33%	$23.\dot{3}\%$
R31-R100	2	1	7%	$3.\dot{3}\%$

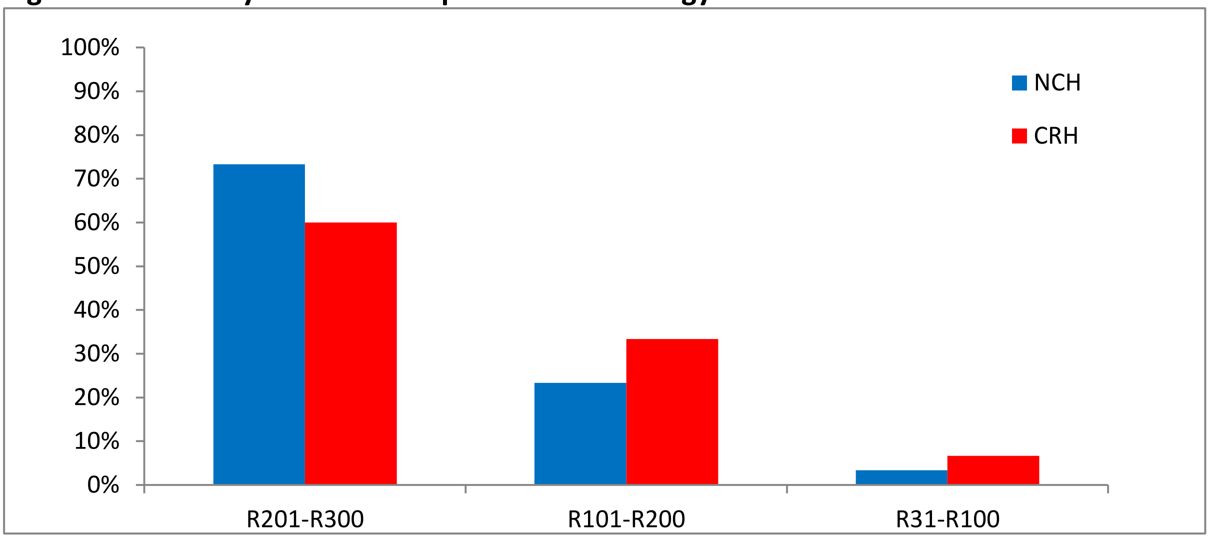
The survey reveals that the difference in the amount of money spent by the CRHs and NCHs in winter is significant, with 20% of the NCHs spending between R400-R500 per month on fuel versus 7% for the CRHs. In the R300-R400 bracket, 60% of the NCHs use this amount per month versus 47% for the CRHs. There is thus a substantial savings amount for the CRHs in energy per month in winter (see Figure 12).

Figure 12: Monthly household expenditure on energy in winter



For the amount of money spent on energy per month in summer, 73.3̇% of the NCHs spend R200-R300 a month versus 60% in the CRHs, indicating only a slight energy saving for the CRHs (see Figure 13). These results are intuitive as the energy required for heating in summer would be minimal and would revert to cooling energy. With ceilings providing insulation from the heat, the cooling energy required in NCHs would relate to equipment such as fans. This concurs with the previous studies on energy improvements from ceilings as discussed above.

Figure 13: Monthly household expenditure on energy in summer



Household incomes in the sample were not established; however the 2011 Mamre census indicates that the incomes across the households in the RDP community are fairly similar. The amount of energy expenditure should therefore not be heavily influenced by income differentials. The expenditure on fuels thus highlights the difference in temperature between the two types of houses.

4.2.5. Health

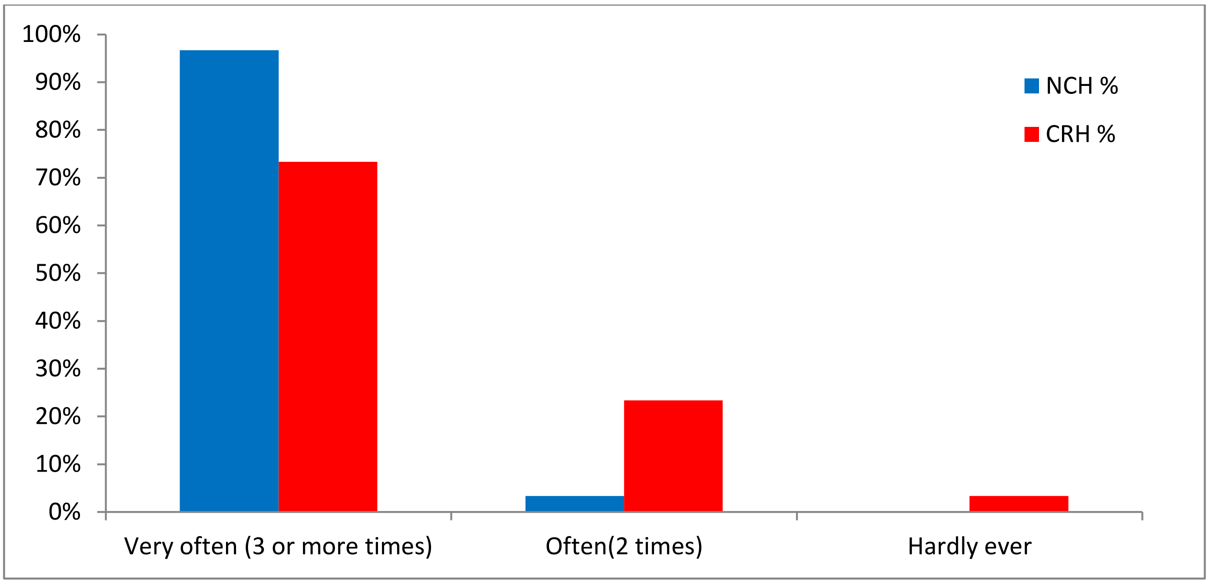
To establish the health impact of ceilings on residents, a series of questions was asked. The first question asked was: *"How often do people suffer from colds/influenza per year?"* The results are shown in Table 14.

Table 14: Cold/influenza frequency

Cold/influenza frequency	CRH	NCH	CRH %	NCH %
Very often (3 or more times)	22	29	73.$\dot{3}$%	97%
Often(2 times)	7	1	23.$\dot{3}$%	3%
Hardly ever	1	0	3.$\dot{3}$%	0%
TB numbers	3	12	2%	8%

In the results from the question, 97% of the NCH residents suffer from colds/influenza 3 or more times a year compared to 73.$\dot{3}$% of the CRH residents (see Figure 14). The health differential between the two types of houses is highlighted by this result.

Figure 14: Frequency of household colds/influenza per year



Regarding TB, the question was asked: *"How many members of your household are being treated for TB?"* The number of TB victims was much higher in the NCHs with 8% of the NCH sample population suffering from this compared to 2% in the CRHs (that is 4 times as many). The actual numbers were 3 TB sufferers in the CRHs and 12 in the NCHs. A caveat here is that it is unknown how long the household member has suffered from TB; they may have contracted TB prior to or after the ceilings being retrofitted.

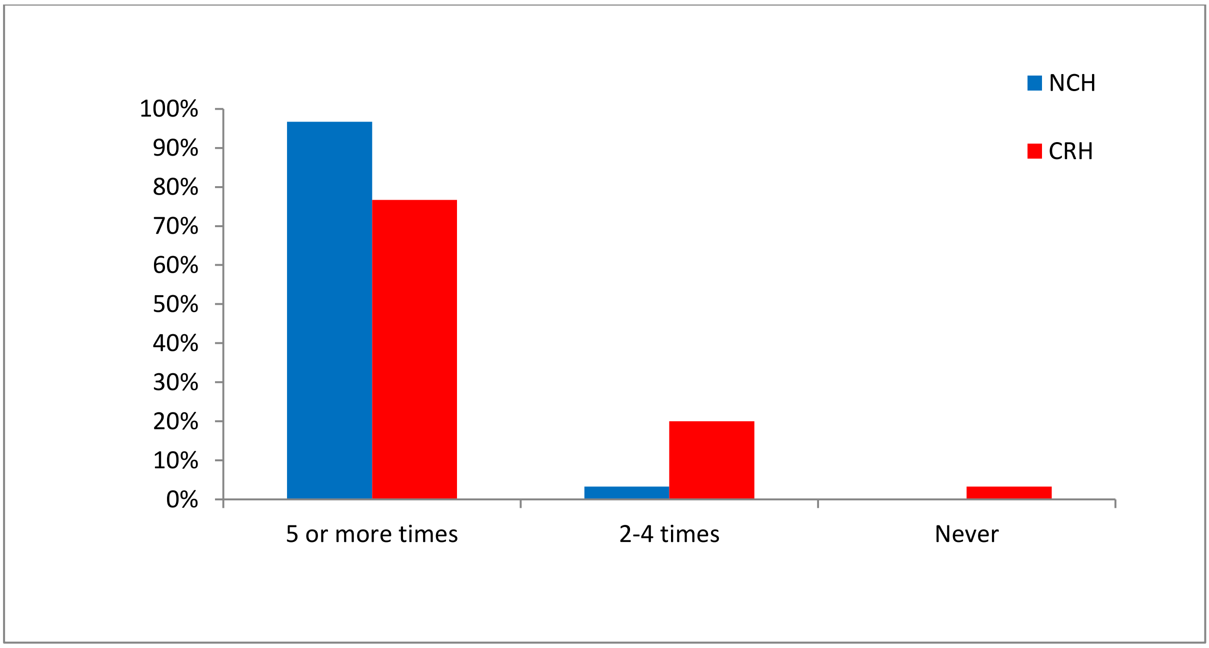
A follow on health question was: *"How many times per year do people seek treatment for respiratory illness?"* The results are shown in Table 15.

Table 15: Respiratory illness frequency

Respiratory illness frequency	CRH	NCH	CRH %	NCH %
5 or more times	23	29	77%	97%
2-4 times	6	1	20%	3%
<2 times	0	0	0%	0%
Never	1	0	3%	0%

The number of times per year people seek treatment for respiratory illnesses reveals a similar pattern, with 97% of the residents in the NCHs indicating 5 or more times a year and only 77% of the residents in the CRHs (see Figure 15). The NCH residents appear to seek treatment for illnesses more often than CRH residents, indicating the potential positive health impact of ceiling retrofits in RDP houses.

Figure 15: Frequency of treatment for respiratory illness per year



The next health question was: *"How often do people suffer from chest/nose/throat infections?"* The results are shown in Table 16 below.

Table 16: Chest/nose/throat infections frequency

Chest/nose/throat infections frequency	CRH	NCH	CRH %	NCH %
Very often (3 or more times)	28	30	$93.\dot{3}\%$	100%
Hardly ever	1	0	$3.\dot{3}\%$	0%
Often (2 times)	1	0	$3.\dot{3}\%$	0%

Again, the CRH residents indicated a lower occurrence of throat, chest or nose infections, with $93.\dot{3}\%$ affected 3 or more times a year versus 100% for NCH residents. This result is not as strong as previous health questions.

In summary, for the results regarding the health questions, the ceiling retrofits in the CRHs make a considerable difference with fewer infections, colds, TB counts and influenza compared to the NCHs. This improvement in health is strengthened when looking at how the ceilings were assigned. The ceilings were allocated to the elderly, unemployed, physically disabled and single-parented households, where the risk of poor health is higher. However, results from this survey show that this group encompasses healthier homes on average. This confirms the previous results on health improvements from ceiling retrofits in the Mamre, Cato, Kuyasa and Cosmo City studies.

4.2.6. Medical

Regarding the medical questionnaire (Table 17), the numbers represent the responses for each type of house per year. The absolute difference is NCH less CRH and the percentage difference is (NCH-CRH)/ [(NCH+CRH/2)] as a percentage. The questions involved asking: *"How many times per year do people in the household seek treatment for respiratory illnesses?"* and *"How often do you and your family get medical care for respiratory illnesses from the following medical sources per year?"* The TB visits were separated out to see if they made a difference to the findings.

Table 17: Medical Questionnaire

Medical Questionnaire	CRH	NCH	Absolute Difference	% Difference
Total medical visits (doctor/pharmacy/ community/clinic/hospital excl. TB)	251	270	19	7%
Total resident numbers (excl. TB)	122	98	24	22%
Medical visits per person (excl. TB)	2.06	2.76	0.70	29%
Medical visits per household (excl. TB)	8.37	9.00	0.63	7%
Total medical visits (doctor/pharmacy/ community/clinic/hospital incl. TB)	281	416	135	39%
Total numbers of residents (incl. TB)	131	148	17	12%
Total medical visits per person (incl. TB)	2.15	2.81	0.66	27%
Total medical visits per household (incl. TB)	9.37	13.87	4.50	39%
Total hospital visits for households	54	72	18	29%
Hospital visits per person	0.41	0.48	0.07	17%
Hospital visits per household	1.80	2.40	0.60	29%
Total clinic visits for all households	165	226	61	31%
Clinic visits per person	1.26	1.53	0.27	19%
Clinic visits per household	5.5	7.53	2.03	31%

The total number of medical visits per year, excluding TB, was 270 according to the 30 NCHs and 251 for the 30 CRHs, a 7% difference (see Figure 16). When considering the number of visits per person per year, 2.76 were recorded for the NCHs versus 2.06 for the CRHs, a 29% difference. The number of medical visits per household was 9 and 8.37 for NCHs and CRHs respectively, a 7% difference.

The total number of medical visits per year including TB was 416, according to the 30 NCHs and 281 for the 30 CRHs, indicating a dramatic positive difference in health of 39% for ceiling retrofits. This is shown clearly by the number of visits per person per year (see Figure 17). Including TB patients, there were 2.81 visits per person per year in NCHs versus 2.15 visits per person per year in CRHs, a 27% difference.

The NCHs visited a medical facility (including TB) 13.87 times a year per household versus 9.37 for the CRHs, which was 4.5 times more per year for the NCHs and a substantial 39% difference (see Figure 18). This again emphasises the positive effect of ceilings on the health of households. The total number of hospital visits per year for the 30 NCHs was 72 and for the CRHs was 54, showing a 29% difference. For the “per person and per household hospital visits”, NCHs visited the hospital 0.07 and 0.6 times more frequently than CRHs (a 17% and 29% difference respectively). For clinics alone, CRH residents visited 165 times a year, while NCH residents visited 226 times a year, a substantial 31% difference. The NCHs visited the clinics 0.27 and 2.03 times more often annually than CRHs, per person and per household respectively (a 19% and 31% difference respectively).

Figure 16: Absolute medical visits for the NCHs and CRHs

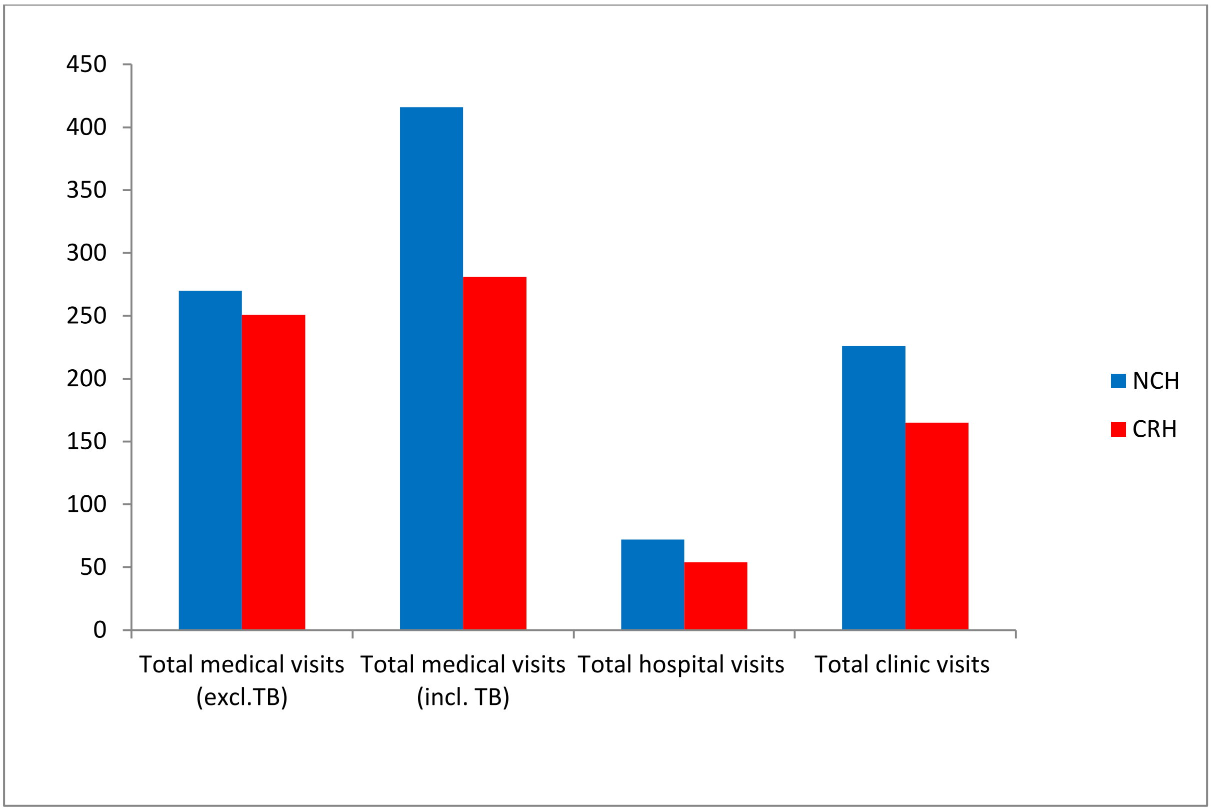


Figure 17: Medical visits per person for the NCHs and CRHs

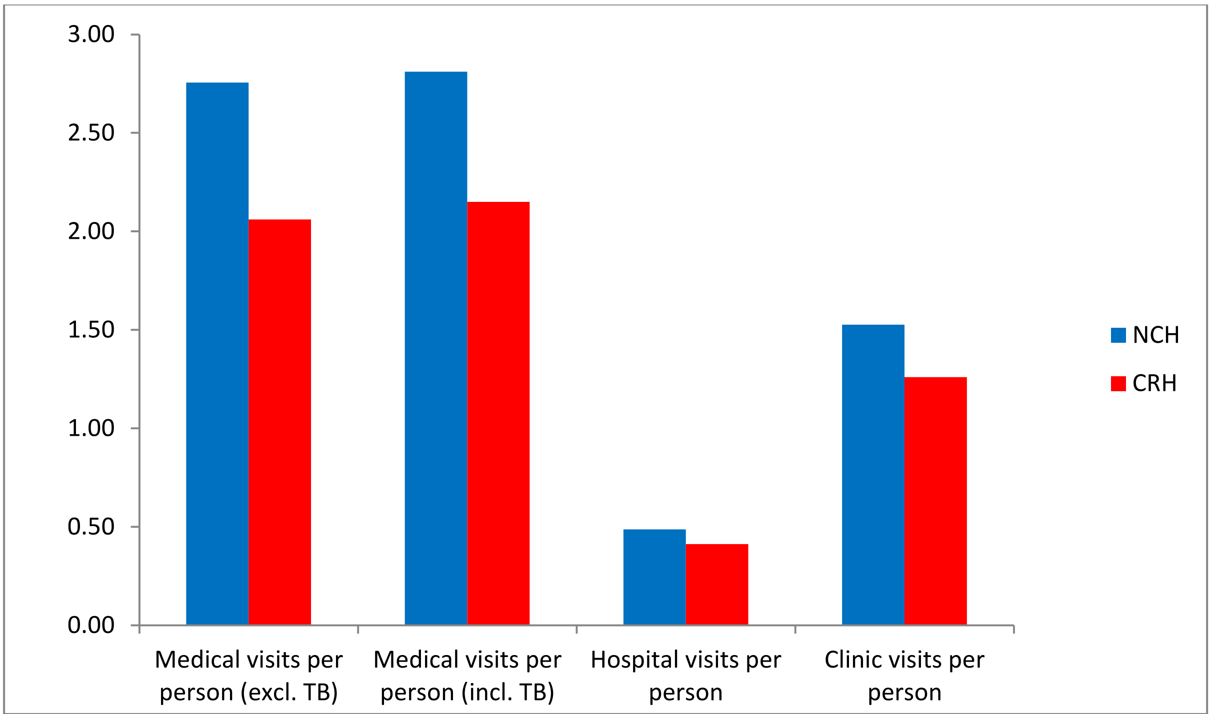
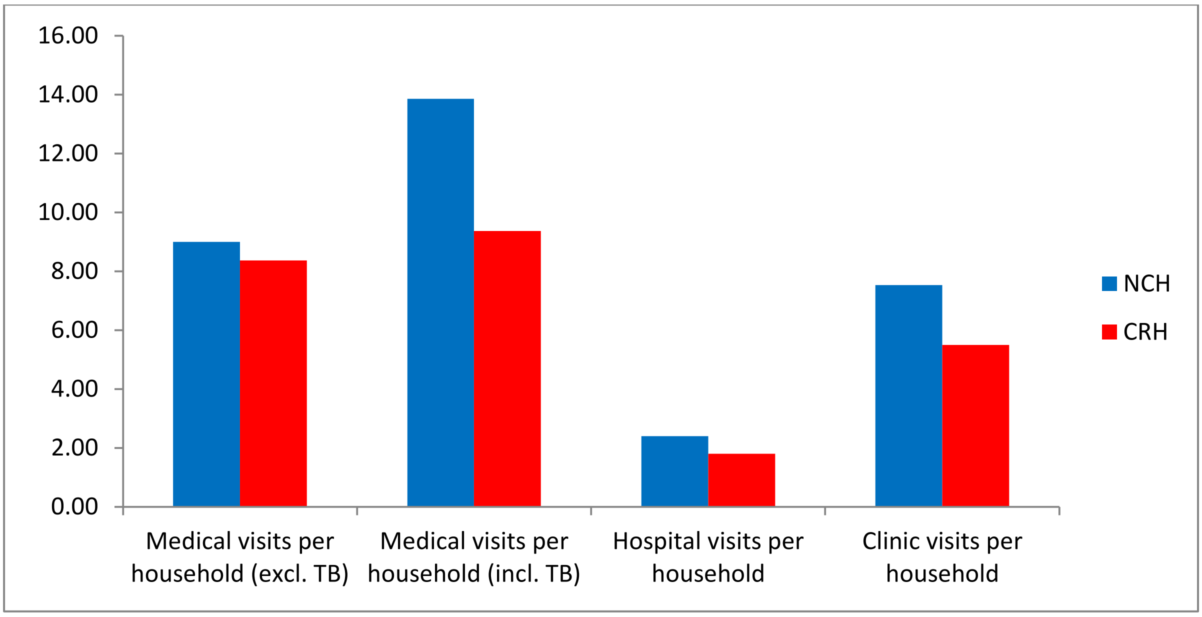


Figure 18: Medical visits per household for the NCHs and CRHs



Overall, this study on ceiling retrofits strongly supports the findings from Phillips, Silver, & Rowswell (2011). As discussed, preference was given to the more vulnerable groups within the community for ceiling retrofitting. This population group is more susceptible to health issues and would potentially use the clinic and hospitals more often than other better-off, employed, two-parented and healthy Mamre households that did not receive ceilings. The more vulnerable ceiling group would also be likely to require more energy to heat their homes and keep them comfortable than the healthier, less vulnerable group. The impact of the ceilings on health and energy is therefore particularly noteworthy when comparing it to the base from whence it comes. The medical visits are consistently more frequent in the NCHs compared to the CRHs.

4.2.7. Ceiling Impact

The ceiling impact was measured by asking the residents their views on the ceiling retrofit programme. The first question on the ceiling impact was: "*How important are ceilings?*" The results are shown in Table 18 below.

Table 18: Importance of ceilings

Importance of ceilings	CRH	NCH	CRH %	NCH %
Very important	27	30	90%	100%
Somewhat important	2	0	7%	0%
Not important	1	0	3%	0%

90% of the CRHs felt that the ceilings were important, though they often complained about other forms of defects discussed previously, including: damp walls, lack of plaster, damp floors, poorly constructed windows and doors, lack of waterproofing and insulation. A behavioural instinct could be linked to the desire for ceilings for the NCHs. Households without ceilings may be coveting ceilings as they have not received one, whilst their neighbour has. This may have influenced their desire for retrofitted ceilings more than a health or energy saving reason.

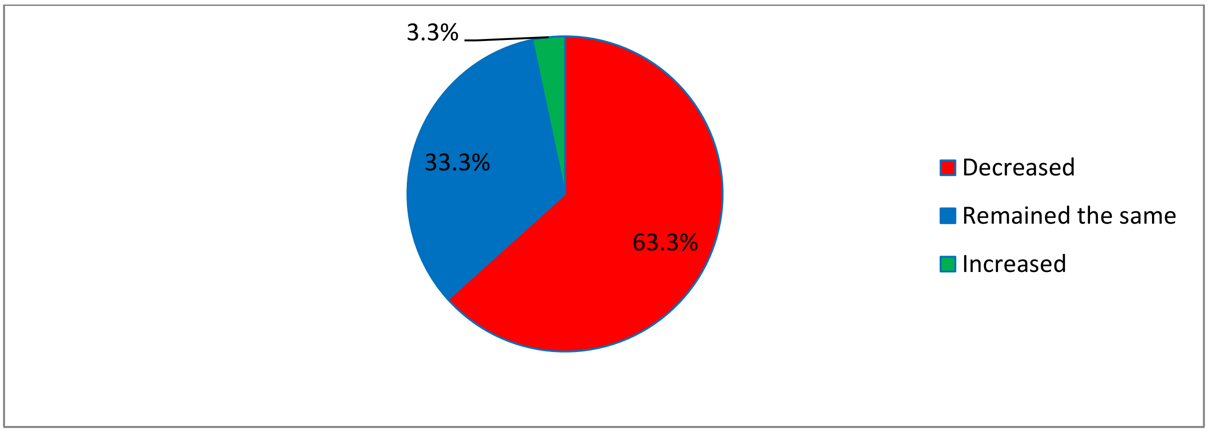
The next question was: “Have the illnesses increased or decreased with ceilings?” The results are shown in Table 19.

Table 19: Ceiling impact on illness frequency

Ceiling impact on illness frequency	CRH	CRH %
Decreased	19	$63.\dot{3}\%$
Remained the same	10	$33.\dot{3}\%$
Increased	1	$3.\dot{3}\%$

A relevant health impact is shown by the results from this question, with $63.\dot{3}\%$ of the CRHs believing that illnesses have decreased with ceiling retrofits (see Figure 19).

Figure 19: Ceiling installation impact on illnesses



A final impact question was: *“Are you spending more or less on fuel with the ceilings?”* The results are shown in Table 20 below.

Table 20: Fuel expenditure

Fuel expenditure	CRH	CRH %
Unsure	16	53%
More	3	10%
Less	6	20%
The same as before	5	17%

With only 20% of the CRHs believing they are spending less on energy now than before and 53% unsure, an impression is made that they do not believe the ceilings are making such an impact in reducing energy. This specific result could be due to the rampant rise in electricity prices, which has influenced how much the residents are spending on energy, irrespective of the ceiling retrofit. NERSA, the National Energy Regulator for South Africa, approved an increase of 31.3%, in 2009/2010, 24.8% for 2010/2011, 25.8% for 2011/2012 and 16% for 2012/2013 (NERSA, 2014). The amount of energy used may have thus decreased due to ceilings, but the residents are not feeling it in their pockets due to the steep rise in electricity prices.

An area which is hard to measure via surveys is the aesthetically pleasing nature of ceilings. They make a house look better and thus make people feel better. Living under a roof without a ceiling does take away from a pleasant, hospitable home, which can affect a person's productivity and health. A person is less likely to be sociable and invite guests over to a home they are not comfortable in, which could damage the social and thus mental fabric of a society. However, this effect is hard to quantify.

4.2.8. Statistics

With a sample size of 60 out of 400 RDP houses in Mamre, a confidence interval of 12% is attained at a 95% confidence level for statistical analysis. For the 30 CRHs (out of 240), the interval is 17% at a 95% confidence level, whilst for the 30 NCHs (out of 160) the interval is 16% at a 95% confidence level (Creative research systems, 2014).

An analysis of variance (ANOVA) test was run on the data collected. The following results were calculated on two questions:

Question 1: Is there a significant temperature difference between houses with and without ceilings?

The presence of a ceiling in a house keeps the house significantly warmer at night - ANOVA ($F_{1,46}=5.631$, $p>0.0219$). On average, a house with a ceiling is 0.85°C warmer than outside and a house without a ceiling is 0.35°C warmer inside than outside.

In the early morning the temperature difference between indoors and outdoors does not significantly differ between houses with and without ceilings.

Question 2: Do residents without ceilings have more medical visits?

An analysis of covariance (ANCOVA) was performed to investigate if having residents living in houses without ceilings incurred higher medical visits relative to those living in houses with ceilings. The number of residents in the house over the age of 60 was controlled for by including this as a cofactor in the analysis.

The number of people residing in a house over the age of 60 did not significantly alter the relationship between medical visits and the presence and absence of ceilings. The medical visits of residents living in houses without ceilings were significantly higher than those of residents living in houses with ceilings - ANOVA ($F_{,45} = 2.49$, $p > 0.042$).

These results provide substantial evidence that ceilings do play a significant positive role in higher temperatures and fewer medical visits in CRHs.

5. Cost-benefit analysis

5.1. Introduction

A cost-benefit analysis (CBA) is a tool for working out the feasibility of an investment based on its costs and benefits. Most capital projects are evaluated using a discounted cash flow. Analysing energy efficiency is no different to analysing a capital investment project and the same tools will therefore be used in this study. A CBA simply compares all present and future benefits of a project with its present and future costs using a discount rate to bring future values into the present.

There are two types of CBAs, financial and social CBAs. A financial CBA considers the monetary costs and benefits of a project or investment and provides a net present value (NPV) that can be ranked to assist in choosing the best option. A social CBA measures the merit of a project that has an impact beyond the financial scope such as health, environmental and life benefits (Department of Environmental Affairs and Tourism, 2004). In this study, a social CBA will be used. It will thus provide a NPV for the ceiling intervention and a ratio of benefits to costs, where projects with a ratio greater than 1 are seen as favourable projects. The ceiling intervention will pass the resource test if the NPV of social benefits exceeds the NPV of social costs (Department of Environmental Affairs and Tourism, 2004).

5.2. Benefits

When establishing a social CBA, one needs to be able to value certain parts of the ceiling intervention, called co-benefits or positive externalities.

This CBA will be measuring:

- the value in savings from improved health,
- the value of fewer sick days (or more work days),
- the value of savings in energy,
- reduced carbon emissions,
- the value of job creation (measured in terms of the costs of providing similar positions through the Expanded Public Works Programme).

This CBA will not be measuring:

- TB contraction reduction rates,
- the value of the social/hospitable impact in being proud of a home and showcasing it,
- a possible reduction in mortality,
- the value of aesthetically appealing ceilings,
- the value of house price appreciation.

The benefits that will not be measured are the social improvement from being able to host people (which is the benefit of having a warm house that improves the social fabric and connection in a community), the aesthetic benefit of ceilings, the mortality impact and the improvement in housing prices from ceilings. These benefits are extremely hard to value. The difficulties in measuring these co-benefits include trying to monetise these benefits, the double-counting of benefits and the problem of establishing causality between programmes and co-benefits, for example whether the lack of ceilings directly increases the rate of mortality. The TB component will also be left out as one cannot determine when exactly the TB was contracted (before or after installation) and therefore whether ceilings assisted in reducing the TB contract rate directly or not.

The following steps were taken to calculate the NPV of the Mamre ceiling intervention per household:

1. The energy savings were estimated from the ceiling intervention per household per year for two scenarios.
   i. In the first scenario, a standard 8% electricity increase according to NERSA (2014) was applied. This was then converted to a real rate by subtracting the current South African inflation rate of 6% (Trading Economics, 2014) to increase the energy savings by 2%.
   ii. In the second scenario, a 16% increase according to Eskom's expectations was applied for 5 years (NERSA, 2014). The real rate of increase for this scenario was 10%. For the remaining 25 years, a 2% real rate was applied.

2. The health savings were estimated from the ceiling intervention in three ways:
   i. Firstly, as the amount of money saved per year due to reduced hospital visits.
   ii. Secondly, as the amount of money saved per year due to reduced clinic visits.
   iii. Thirdly, as the amount of money saved due to reduced sick days (increased productivity).

   The first two were inflated at a nominal medical inflation rate of 7.5%. Becker (2012) suggests 9%, which has been conservatively reduced to 7.5% less 6% for inflation to provide a 1.5% real inflation rate per annum for 30 years. The third saving was inflated at a 1.5% real rate for wage inflation. These health benefits will be conservative as they focus on financially measurable hospital and clinic visits whilst leaving out the other medical visits, which are also more prevalent in the NCHs.

3. The value of the job creation component of the ceiling retrofit was estimated and inflated at a real rate of 1.5% (7.5% - 6%) per annum for 30 years. This was based on a wage inflation of 7.5% (Money Web, 2013).

4. The reduced carbon emission benefit was estimated by taking suppressed energy generation from energy savings. This benefit was multiplied by 0.77 to account for the

fact that 77% of South Africa's energy generation is from coal, as opposed to other non-carbon-based energy generation (Eskom, 2014). This is then inflated at a real rate of 2%, based on NERSA's electricity increase of 8% (8% - 6%) per annum over 30 years.

5. These benefits were then discounted by the discount factors to get the present value (PV) of these savings.

6. The total benefit per ceiling was calculated by adding up the six individual benefits.

7. The NPV per ceiling was calculated by subtracting the costs of the ceiling intervention.

8. The CBA of the ceiling intervention was considered over 30 years. The standard economic life of a low-cost RDP house is 50 years, however with the RDP houses in Mamre built in 1997, 17 years ago, a conservative estimate of 30 years was used (Winkler et al, 2002).

9. This NPV can be scaled up to a community, provincial or national level by multiplying by the number of households still requiring ceilings.

5.3. Costs

There was only one cost linked to the ceiling project. This was calculated by taking the cost of the ceiling parts and adding it to the labour costs for installing it.

The initial cost of installing a ceiling with parts was estimated at between R6,500 and R7,500 in 2010 (SEED, 2010). The average of these two amounts, R7,000, has been used as the initial cost. The 2013 cost was generated using a 6% inflation rate from the base year of 2010, calculated as R8,337.

The labour component was calculated at R178 (Pay scale, 2014) per employee per day over 3 months for 17 employees, divided by the remaining 160 NCHs. This is based on the Mamre labour figures used in the retrofitting programme. This equated to R1,191 per ceiling in labour costs. The actual labour cost of the ceiling retrofit was multiplied by 0.6 – the economic cost of unskilled labour in South Africa (Bicak et al, 2004). This will act as a shadow wage.

Economic cost of the labour: R1,191 * 0.6 = R715.

Total economic cost of the ceiling retrofit: R8,337 + R715 = R9,052.

This was comparable to the Mamre project, which cost R1.9 million ÷ 240 CRHs = R7,917 in 2010, which equates to R9,429 per ceiling in 2013 Rands.

5.4. The discounting factor

A critical component of a CBA is the discount rate. Using a discount rate converts future money into a PV and one can then compare future costs and benefits. Financial and economic discount rates differ. The financial discount rate is linked to an analysis done from a private investor's point of view. It considers the actual costs of borrowing and the actual returns on alternative investments in the market. The economic discount rate is a measure of how society as a whole values present over future consumption. An economic discount rate is used to reflect the opportunity cost to society, rather than to individuals (Reid, 2009). This CBA focused on an economic discount rate.

The South African government and South African Reserve Bank use an 8% economic discount rate to measure investment projects. This CBA will do the same with 8% as the base case, although Ramsey and Weitzman suggest a much lower social discount rate, closer to real per capita income growth rates (Economics of Climate Change, 2006). The reason that the government uses such a high rate is to prevent the state from crowding out private investment opportunities. If it used a lower rate, a much larger number of projects would be approved by the government, which may lead to the public sector overriding the private sector. They thus keep the hurdle rate at a sustainable level of 8%.

A sensitivity test will be used to determine if the benefits outweigh the costs with a real discount rate of 2%, 4%, 6% and 10% respectively. These discount rates are called exponential time consistent rates. This will test the robustness of the model at a higher rate where the future benefits will not be as large (short-term focused) and a lower rate where the future benefits are extremely important (long-term focused) (Economics of Climate Change, 2006). The lower rates are more critical on the grounds that this is closer to the growth in real per capita incomes in South Africa of 1.67% (World Bank, 2014). CBAs that are based on high discount rates tend to favour projects with short-run benefits over long-run benefits. As the discount rate drops, so projects with benefits in the long run will grow in importance. A study of 9 developing countries in South America found that the appropriate social discount rate for a 25 year horizon was 4.4% (World Bank, 2008).

An alternative to an exponential time consistent rate that was considered was a hyperbolic discount rate, which is time inconsistent. The valuations will drop very rapidly for short time periods and very slowly for long time periods. There is thus a change in the rate over time, with high rates in the early years and lower rates in the later years. The hyperbolic discount rate is often used with long time horizons, such as measuring the impact of carbon on global warming over 100 to 200 years. With only a 30-year time horizon, this model does not justify a hyperbolic discount rate.

While the CBA may reveal a positive value for ceiling interventions, understanding that RDP households are generally poor and may not have the finances to purchase this ceiling instalment, or have access to low-cost credit, is paramount. This is a major concern as these interventions have a higher initial cost with a minimal recurrent or maintenance cost. With a consumer discount rate of 30% taken into account, most of the interventions (including ceilings, walls and solar water heaters) may not provide a benefit and will thus require subsidising. Therefore, a discount factor of 30% will also be tested to reflect the high rate of credit potentially faced by consumers.

5.5. Composition of the CBA model

The following assumptions were used to calculate and build the CBA. According to the World Bank (2014), the growth in real GDP per capita for South Africa was 1.67% per year, over the period 2010-2012. The inflation rate used in this model was conservatively linked to this rate with a real inflation rate of 1.5% for wages and health, other than the real electricity inflation rate of 2%.

5.5.1. Energy benefits

Taking the energy expenditure in winter and summer and averaging them for the 30 CRHs and 30 NCHs, the ceilings are saving a household R376 per year in energy consumption.

i. For the first scenario, this saving was multiplied by the real inflation rate of 2% (NERSA, 2014) over 30 years to calculate the value of energy savings for the ceiling over its lifetime. This was then discounted at the real discount rates of 2%, 4%, 6%, 8%, 10% and 30%, to create a range of PV benefits for energy savings.
ii. The energy savings were calculated for the second scenario with a real price increase of 10% in electricity for 5 years and 2% for 25 years. The robustness of this model was tested using the various discount rates discussed above.

CRH Energy Benefit: R376

5.5.2. Health benefits

i. On average, the CRH resident visits the hospital 7% (0.07 times) less than the NCH resident per year. This confirms the findings in the previous Mamre paper where illnesses, asthma and medical costs dropped dramatically in the ceiling households over a year. The total hospital budget for the Western Cape was R6.5 billion in 2013 according to the Health Department. The recorded 322,954 attendances during the year[1] equates to a hospital cost of R20,205 per person in the Western Cape. With 30-40% of hospital admissions related to respiratory illness in South Africa (Davies & Zar, 2007), the respiratory cost will be conservatively weighted at 30% to remove the cost of trauma surgery and other operations. A value for the benefit of CRHs from reduced hospital visits was calculated at R424 per person by multiplying the hospital cost by 30% and by 7%. This is then multiplied by 4.36, the average number of residents in the CRHs, to create a total ceiling benefit per household. This captures

[1] Personal email from Dr S. Fourie, Western Cape Department of Health, Director of Specialised Services, 2014

the overall societal benefit of ceilings from reduced hospital visits as hospital payments vary according to income and status.

CRH Hospital benefit: R20,205 * 30% * 0.07 * 4.36 = R1,850.

This was an additional hospital benefit for CRH residents per year. Using a real inflation rate of 1.5%, one can calculate the savings in hospital visits from the ceiling intervention, discounted at the various discount rates.

ii. For the clinic benefit, data gathered from the Western Cape Government revealed that the budget for the Mamre clinic was R 4.8 million for 2013 and that the number of attendees was 36,095 people[1]. This equates to a cost per person of R135 for the clinic component. This was multiplied by 27% (0.27) - the number of times CRH residents visited the clinic less than NCH residents per year. The benefit was then multiplied by 30%, the percentage of respiratory related illnesses in South Africa (Davies & Zar, 2007). A value for the benefit of CRHs from reduced clinic visits was calculated at R11 per visit. This is then multiplied by 4.36, the average number of residents in the CRHs to create a total ceiling benefit per household. This captures the overall societal benefit of ceilings from reduced clinic visits as individual clinic payments vary according to income and status.

CRH Clinic benefit: R135 * 30% * 0.27* 4.36 = R48.

This was then expanded over 30 years at a real inflation rate of 1.5% and discounted at the various discount rates.

iii. For the reduced loss of income benefit, if the average monthly household income in Mamre in 2011 was R6,991.68 (Census, 2011), projecting it forward to 2013 with 6% inflation provided a figure of R7,855.85 per month, or R94,270 per year (Western Cape Government, 2011) .This was then divided by 250 (average number of work days per year) to create a daily income per household of R377.08. The daily income over 30 years was worked out with a real inflation rate of 1.5% (7.5%-6%) going forward. This was multiplied by 4.5 for the reduced total medical visits a year in the CRHs. In South Africa, approximately 3.5% to 6% of sick days lead to a loss of income (Human Capital Review, 2009). Therefore, an average of 4.75% loss of work weighting was used to calculate the gain in income due to CRHs. The household income is, however, subject to subsidies from the government which are not affected by sick days. In order to account for this, a subsidy ratio was calculated. In the Mamre sample there were 11 elderly people (over 60) and 112 youths (under 18) in total for the 60 households. Per household that is 0.183 elders and 1.866 youths. The current subsidies for the elderly and youth are R1,350 per month and R320 per month (South Africa.info, 2014). Therefore, the grant subsidies in the sample would

[1] Personal email from Dr S. Fourie, Western Cape Department of Health, Director of Specialised Services, 2014

be 0.183 * R1,350 = R247 for the elderly per month per household and 1.866 * R320 = R597 for the youths per month per household or R844 in total. The percentage of the subsidy over the household income figure is thus R844/R7856 = 11%. To account for additional subsidies such as disabilities, the percentage figure will be increased to 15%. Thus, 85% of the household income is assumed to be non-subsidy related.

CRH reduced loss of income benefit per year: R377.08 * 4.5 * 4.75% * 85% = R69

This was then expanded over 30 years at a real inflation rate of 1.5% and discounted at the various discount rates. It should be noted that the sick days can be valued for both adults and children as the adults would need to look after the children at home for a certain number of sick days, whilst an adult who is sick will also need to stay at home for a certain number of days.

5.5.3. Job creation benefits

In the initial retrofit programme, 18 local residents were trained and worked for a year to install and retrofit 240 ceilings and administer the programme. From this training, 8 full-time jobs were created in the community. With a further 160 households to be retrofitted in the Mamre area, an additional 12 temporary jobs and 5 full-time jobs will be created. These jobs are invaluable to an area with an unemployment rate of 27% (Western Cape, 2011). The spill-over effects to the families of these employees and boost to the local economy is vital. With such high unemployment, the increase in labour in one sector will not displace any labour in another sector; there will be no loss of output.

For the job creation benefit, the benefits that will be passed on to society from the ceiling retrofit programme were analysed. Future ceiling retrofits will save citizens tax money utilised in job creation initiatives. A succinct starting point would be to use the Expanded Public Works Programme (EPWP) as a proxy for the jobs benefit structure. This proxy provides a government-revealed preference for the overall benefits of a job created; including the economic benefit, spill-over benefit from a derived household income, reduced crime, family welfare and growth in taxes/spending.

The EPWP is an initiative stimulating job creation and working opportunities, whilst alleviating poverty through all spheres of government and state-owned enterprises, including provinces and municipalities. The programme entails the provision of large budgets for projects in community development, culture, environment, society and infrastructure.

In the Western Cape, the 2012/2013 budget for EPWP was R2.1 billion according to the Department of Public Works (2012). With this budget, the Western Cape

Government created 109,482 jobs (South African Government Online, 2013). Thus, the cost of each job created was R19,208. With the future ceiling retrofit project creating 12 temporary and 5 permanent jobs, the calculated benefit to society from this intervention is the amount it is saving the Western Cape Government in terms of generating EPWP jobs. The temporary jobs provide work for 3 months of the year (3/12 = 0.25). The temporary job benefit was therefore multiplied by 0.25. The probability of an unemployed person joining the EPWP in the Western Cape needs to be established. With an unemployed population of 571,750 (StatsSA, 2014) and 109,482 jobs created via the EPWP in 2013, the probability of an unemployed person receiving an EPWP job is 109,482/571,750 or 0.19 in the Western Cape. The temporary job benefit and permanent job benefit were multiplied by this probability factor to create a realistic job creation benefit take up from the ceiling retrofit programme. These two amounts were added together and divided by the future 160 ceilings in Mamre to determine the job impact per household in year one.

Temporary job benefit: 12 * R19,208 * 0.25 * 0.19 = R10, 949

Permanent job benefit: 5 * R19,208 * 0.19 = R18,248

CRH job benefit in year 1: R29,197 / 160 = R182

The temporary job benefit was only accounted for in year one. The permanent job creation impact was inflated by 1.5% for 30 years and divided by 160 to calculate a household benefit.

5.5.4. Carbon emission benefits

i. Benefits through suppressed energy generation:

For the carbon emissions benefit, the rand per kWh rate in Cape Town was calculated at R1.58 (City of Cape Town, 2014) and this was divided by the energy savings per household per annum of R376. This provided the amount of kWhs saved per annum of 238kWh. This was then multiplied by the South African GHG emission factor of 0.99kg of CO_2/kWh in 2011 (Urban Earth, 2012) to give the value of emissions saved of 236kg per household per year. With a carbon tax of R0.12/kg or R120/tonne currently being put forward for South Africa (Environmental and Energy Study Institute, 2012), the savings are priced at R28 per year per household for the CRH.

The assumption here is that the carbon tax will be similar to the social cost of emissions at this point in time. In actual fact, the cost of carbon emissions is much greater. An exact number is hard to define given the externalities involved and the timeline for cleaning up the atmosphere. South Africa's long-term scenario prices it at R750/tonne, Stern's review prices it at R800/tonne, and the IPCC at R650-

R1300/tonne (Department of National Treasury, 2010). Taking an average of the three, the amount calculated is R888/tonne of carbon. With this in mind, the carbon savings from a CRH is in fact R209.35 per year per household. With 77% of energy generation stemming from coal in South Africa, the R209.35 is multiplied by 0.77 to establish the carbon emissions savings from suppressed energy generation of R161.

CRH Carbon Benefit: R376 / 1.58 * 0.99 * 0.888 * 0.77 = R161

ii. Carbon emissions from ceiling construction and installation:

It would be remiss to not take into account the carbon emissions from the ceiling materials, their construction and installation. Per ceiling, the volume of plasterboard used is 5.4mm * 40m^2 = 0.216m^3 of board. The density of board is 800kg/m^3 and the carbon emissions factor of board is 0.38kg of carbon per kg of board (Hammond & Jones, 2006). The carbon footprint is thus 0.216 * 800 * 0.38 = 65.66kg of carbon per ceiling. For the glass wool insulation, the volume of wool used is 50mm * 40m^2 = 2m^3 of wool. The density of wool is 12kg/m^3 and the carbon emissions factor of wool is 1.35kg of carbon per kg of wool (Hammond & Jones, 2006). The carbon footprint is thus 2 * 12 * 1.35 = 32.4kg of carbon per kg per ceiling. Overall, carbon is thus 98.06kg per ceiling. The transport carbon footprint in construction averages 7% of GHG for a project (Landry, 2011). Thus total carbon emissions are 98.06 * 1.07 = 104.92kg for ceiling transport and installation. With a cost of R0.89 per kg of carbon (R888/tonne), the total cost of carbon emissions per ceiling installation is R93.

Plasterboard: 0.216 * 800 * 0.38 = 65.66kg

Glass Wool: 2 * 12 * 1.35 = 32.4kg

Transport included: 98.06kg * 1.07 = 104.92kg

Carbon emissions cost: 104.92 * 0.888 = R93

Net benefit through suppressed energy generation:

The net carbon benefit through suppressed energy generation is thus R68

Net Benefit: R161 – R93 = R68

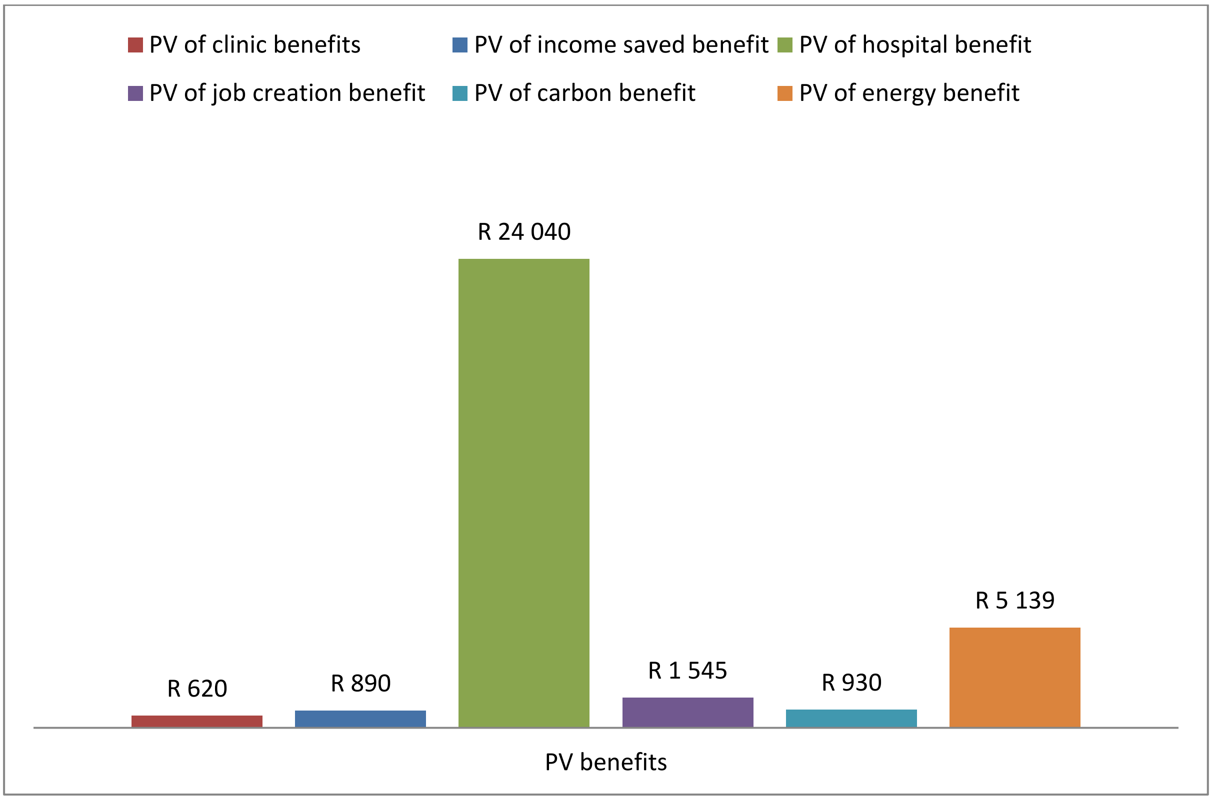
This is inflated at a real rate of 2% per annum (first scenario electricity price increase) for 30 years and discounted accordingly.

5.6. Results

5.6.1. Present Values

All current values are given in real (not nominal) 2013 Rands. With the calculations and assumptions above taken into account, a total PV benefit of R5,139 per CRH was uncovered for the energy savings alone (first scenario) with a benefit to cost ratio (B:C) of 0.57. For the income saved, a PV benefit of R890 was calculated (B:C of 0.1) per CRH, for the hospital PV benefit it was R24,040 (B:C of 2.66), for the job creation PV benefit it was R1,545 (B:C 0.17), for the carbon PV benefit it was R930 (B:C 0.1) and for the clinic PV benefit it was R620 (B:C 0.07). This was all calculated at a standard 8% discount rate (see Figure 20) per CRH.

Figure 20: Total PV benefits at 8% discount rate.



With the cost of the ceiling installation of R9,052 taken into account, the NPV for each component individually is -R3,913 for energy, -R8,432 for the clinics, -R8,162 for the income saved, R14,988 for hospitals, -R7, 507 for jobs created and –R8,122 for carbon savings at an 8% discount rate per CRH.

5.6.2. Total NPVs for first energy scenario

If the energy benefits for the first energy scenario, income saved benefits, job creation benefits, clinic benefits, carbon savings benefits and hospital benefits are combined, a total NPV of R24,112 per CRH was achieved and a significant B:C of 3.66 was discovered (see Figure 21):

8% discount rate - NPV of R24,112 (B:C of 3.66)

This provides strong evidence that ceilings are highly beneficial for society with a favourable NPV that passes the resource test. The sensitivity test provides valuable insight with positive

NPVs per CRH across the discount rates (excluding the 30% rate), demonstrating that the ceiling impact is robust (see Figure 21):

2% discount rate - NPV of R59,971 (B:C of 7.63)

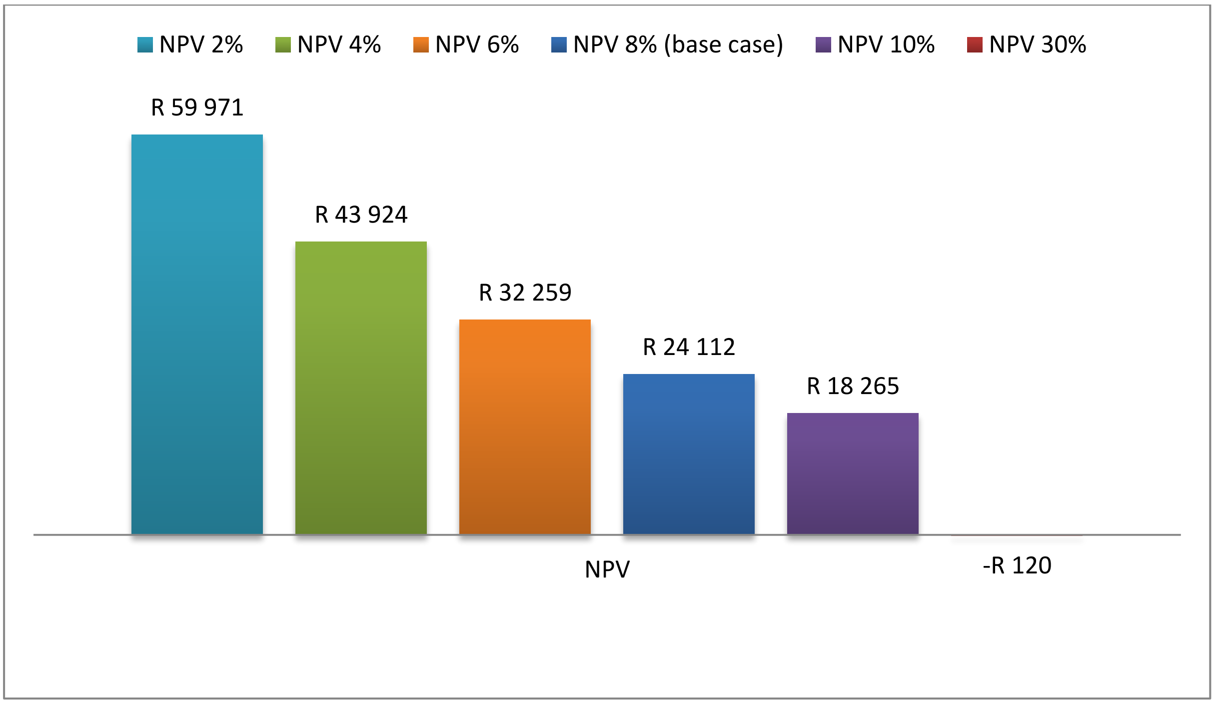
4% discount rate - NPV of R43,924 (B:C of 5.85)

6% discount rate - NPV of R32,259 (B:C of 4.56)

10% discount rate - NPV of R18,265 (B:C of 3.02)

30% discount rate - NPV of -R120 (B:C of 0.99)

Figure 21: Total NPV at various discount rates (scenario 1)



5.6.3. Total NPVs for second energy scenario

For the second energy scenario combined with the income saved, carbon saved, jobs created and health benefits, the following NPVs were calculated (see Figure 22):

2% discount rate - NPV of R63,471 (B:C of 8.01)

4% discount rate - NPV of R46,527 (B:C of 6.14)

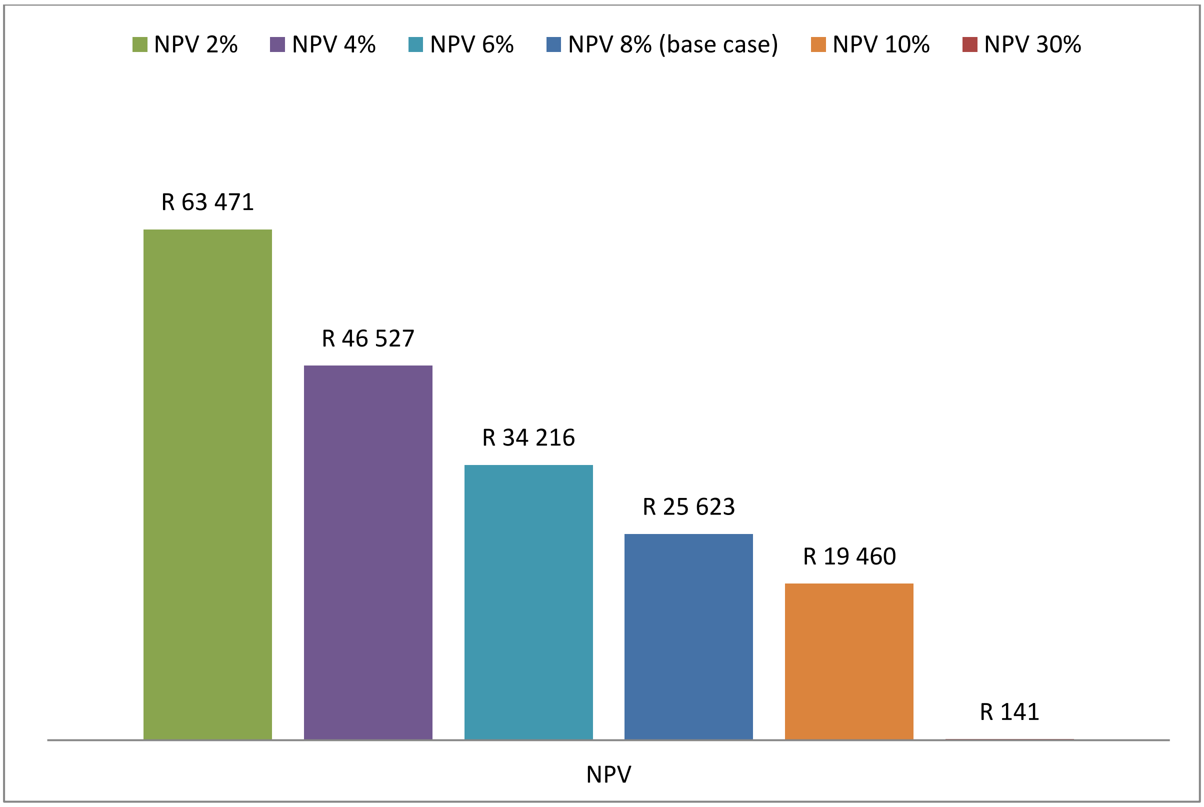
6% discount rate - NPV of R34,216 (B:C of 4.78)

8% discount rate - NPV of R25,623 (B:C of 3.83)

10% discount rate - NPV of R19,460 (B:C of 3.15)

30% discount rate - NPV of R141 (B:C of 1.02)

Figure 22: Total NPV various discount rates (scenario 2)



These figures above highlight that, with an electricity price hike, the NPVs from the ceiling retrofitting programme are similarly positive with a NPV of R25,623 per CRH with a 8% discount rate.

5.6.4. First energy scenario

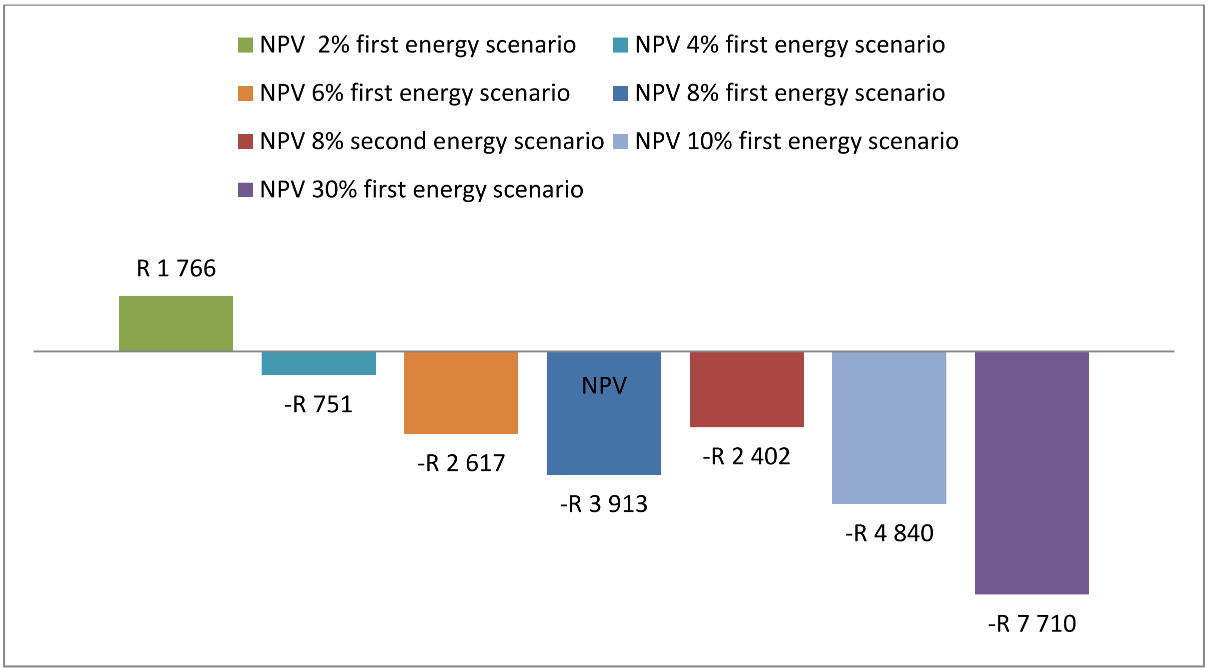
For the energy benefits component alone, the following NPVs were calculated per CRH at various discount rates. These are based on the first energy scenario with a real price increase expectation of 2% for electricity (see Figure 23):

2% discount rate	**-**	***NPV of R1,766***	***(B:C of 1.2)***
4% discount rate	**-**	***NPV of -R751***	***(B:C of 0.92)***
6% discount rate	**-**	***NPV of -R2,617***	***(B:C of 0.71)***
8% discount rate	**-**	***NPV of -R3,193***	***(B:C of 0.57)***
10% discount rate	**-**	***NPV of -R4,840***	***(B:C of 0.47)***
30% discount rate	**-**	***NPV of -R7,710***	***(B:C of 0.15)***

5.6.5. Second energy scenario

In the second energy scenario, the NPV for energy alone was –R2,402 (B:C of 0.73), at a 8% discount rate (see Figure 23).

Figure 23: NPV for energy at various discount rates and electricity prices



In summary (see Table 21), even when excluding a number of unquantifiable co-benefits (as discussed in the benefits section), the ceiling installation indicates a positive NPV at the majority of discount levels and for both energy scenarios. It is therefore a viable project. Other CBA studies for ceiling retrofits support this result.

5.6.6. Internal rate of return

The Internal Rate of Return (IRR) is the discount rate at which the PVs of both benefits and costs are equal. Projects should have an IRR greater than the discount rate to be considered a good investment. In the first energy scenario, the base discount rate was 8% and the IRR was 29.6% for total benefits and costs, giving the ceiling retrofitting project a resounding positive impact.

5.6.7. CBAs from other studies

The Sustainable Development Network (2013) compiled a cost-effectiveness analysis to see whether sustainable housing developments are too expensive in the life-cycle model. The results established that the model was highly cost-effective. The benefits included utilising renewable energy, improving health, reducing energy expenditure, reducing travel costs (with closer locations to development nodes) and creating a quality community environment. The life-cycle model presented a NPV of R4,666 over 30 years, at a 9%

discount rate, taking into account a capital outlay of R104,620 for changes to the interior and exterior of the houses. These included: planting trees and shrubs, improving ecological design, installing insulation fixtures such as SWHs, water and sanitation changes and infrastructure upgrades amongst others (Sustainable Development Network, 2013).

In the Winkler et al (2002) study looking at energy savings, ceilings presented a NPV of R881 (R1,672 in 2013 Rands), wall insulations presented a NPV of R1,026 and SWHs presented a NPV of R351 per household. When dividing up the effect of the intervention across regions (Western Cape, Gauteng and KZN), the NPV does not vary much as the energy savings in Gauteng due to colder winter nights are offset by higher installation costs. Winkler's retrofit NPV figure is much lower than this study as it focuses only on energy savings whilst leaving out the health, carbon and jobs benefit. When comparing energy to energy savings, Winkler's figure is slightly higher than this study as it was taken over a 50 year timeline and not the 30 year timeline used in this study. A more accurate lifespan for a ceiling retrofit is 30 years.

Table 21: Summary of CBA per ceiling

Assumptions	Indicators	Total benefit for 30 years	NPV (less cost of ceiling installation	Benefits: cost ratio
Ceiling cost				
R7000 (2011) initial cost for a ceiling = R8337 in 2013. Labour = ((160 * 0.25 * 17 *R178)/160) * 0.6 = (R1191*0.6) + R8337= R9052	Cost of a ceiling is R9052			
Energy benefits				
R376 per year savings. Assumption 8% electricity hike per NERSA, real rate of 2%	Total benefit for first energy scenario	R 15 254		
R376 per year savings. Assumption of 16% electricty hike and a real rate of 10% for 5 years, 2% real rate for 25 years	Total benefit for second energy scenario	R 20 281		
Present value for energy benefits				
Discounted at 8% (Base rate)	PV benefit for first energy scenario	R 5 139	**-R 3 913**	0.57
Discounted at 8% (Base rate)	PV benefit for second energy scenario	R 6 650	**-R 2 402**	0.73
Discounted at 30% consumer rate	PV benefit for first energy scenario	R 1 342	**-R 7 710**	0.15
Discounted at 2%	PV benefit for first energy scenario	R 10 818	**R 1 766**	1.20
Discounted at 4%	PV benefit for first energy scenario	R 8 301	**-R 751**	0.92
Discounted at 6%	PV benefit for first energy scenario	R 6 435	**-R 2 617**	0.71
Discounted at 10%	PV benefit for first energy scenario	R 4 212	**-R 4 840**	0.47
Health benefit				
CRH Hospital benefit: R20,205 * 30% * 0.07 * 4.36 = R1,850.	Total hospital visit savings	R 69 445		
CRH Clinic benefit: R135 * 30% * 0.27* 4.36 = R48.	Total clinic visit savings	R 1 790		
CRH reduced loss of income benefit per year: *R377 * 4.5 * 4.75% * 85% = R69*	Total productivity savings due to being healthy	R 2 572		
Net present values for health				
Discount rate 8%	PV benefit for hospital visits	R 24 040	**R 14 988**	2.66
Discount rate 8%	PV benefit for clinic	R 620	**-R 8 432**	0.07
Discount rate 8%	PV benefit for income saved	R 890	**-R 8 162**	0.10
Job creation benefit				
Temporary job benefit: 12 * R19,208 * 0.25 * 0.19 = R10, 949 Permanent job benefit: 5 * R19,208 * 0.19 = R18,248 CRH job benefit in year 1: R29,197 / 160 = R182	Total job creation benefit	R 4 350		
Discount rate 8%	PV benefit of job creation	R 1 545	**-R 7 507**	0.17
Carbon saving benefit				
CRH Carbon Benefit: R376 / 1.58 * 0.99 * 0.888 * 0.77 = R161 - R93 = R68 CRH Carbon cost 98.06kg * 1.07 = 104.92 * 0.888 = R93	Total reduced carbon emissions savings	R 2 760		
Discount rate 8%	PV benefit of reduced emissions	R 930	**-R 8 122**	0.10
Total benefit for first energy scenario		**R 96 170**		
	Total PV at 8%	R 33 164	**R 24 112**	3.66
	Total PV at consumer discount rate of 30%	R 8 932	**-R 120**	0.99
	Total PV sensitivity test @ 2%	R 69 023	**R 59 971**	7.63
	Total PV sensitivity test @ 4%	R 52 976	**R 43 924**	5.85
	Total PV sensitivity test @ 6%	R 41 311	**R 32 259**	4.56
	Total PV sensitivity test @ 10%	R 27 317	**R 18 265**	3.02
Total benefit for second energy scenario		**R 101 197**		
	Total PV at 8%	R 34 675	**R 25 623**	3.83
	Total PV at consumer discount rate of 30%	R 9 193	**R 141**	1.02
	Total PV sensitivity test @ 2%	R 72 523	**R 63 471**	8.01
	Total PV sensitivity test @ 4%	R 55 579	**R 46 527**	6.14
	Total PV sensitivity test @ 6%	R 43 268	**R 34 216**	4.78
	Total PV sensitivity test @ 10%	R 28 512	**R 19 460**	3.15

5.7. Macro-economic impact analysis

A macro-economic impact analysis (MEIA) takes into account the ripple effect of a project through an economy in terms of the linkages of the project (Conningarth Economists, 2013). This study focused on the MEIA for the ceiling project in the City of Cape Town economy in terms of the following macro-economic aggregates:

- GDP and economic growth (fewer sick days)
- Employment creation
- Household income savings (energy and health)

This gave the direct, indirect and induced impact of the ceiling project. RDP houses built prior to 2005 were not fitted with ceilings, so an estimated 40,000 RDP houses in Cape Town do not have ceilings. The Western Cape Government plans to roll out a large scale programme to retrofit these outstanding 40,000 RDP houses with ceilings. It is expected that the total cost will be approximately R400 million (R10,000 per ceiling) and this will create over 250 contracting opportunities and more in the production, supply and installation of these ceilings (Western Cape Government, 2013). With a population of 3.5 million in the City of Cape Town, including an informal settlement population of over 400,000, the housing problem is highly acute (Fairhurst & Rowswell, 2011).

The MEIA would thus be R33,164 (Total Present Benefit per ceiling) * 40,000 = R1,327 million with total costs of R400 million leaving a net benefit of over R926 million for rolling this programme out through the Western Cape. On the jobs created side alone, with a R19,208 * 0.19 = R3,649.52 saving per the EPWP calculation, it would create a total benefit of R912,380.

Western Cape MEIA: (R33,164 * 40,000) – 400,000,000 = R926,560,000

Job savings: 19,208 * 0.19 * 250 = R912,380

The benefits for the Mamre community were investigated independently. The 160 RDP houses still requiring a ceiling were multiplied by R24,112 (NPV), this equals a R3,857,920 NPV benefit for the community.

Mamre MEIA: 160 * R24,112 = R3,857,920

This macro-analysis does not take into account the opportunity costs. The R400 million could be used to support shack improvements, provide cleaner and more energy efficient cooking stoves or construct new RDP houses. With a R400 million budget, the Western Cape Government could build 4,651 RDP houses at a cost price of R86,000 a house (Dispatch Online, 2013), could develop 60,606 I-shacks as discussed in the literature review at R6,600 an upgrade (Take Part, 2013) or could buy 519,480 stoves at a cost of R770 a stove

(Sustainable, 2014). While it is hard to measure the cost-benefits across these interventions, finding out what the people want is paramount, with ceiling retrofits regarded as highly desirable by Mamre residents.

5.8. Incentivising ceilings

For most low-cost housing residents, installing energy efficient interventions such as ceilings, fluorescent lighting, wall insulations, roof insulations, SWHs and larger windows is expensive. Their budgets are already stretched with high energy and food costs exacerbated by the steep rise in electricity and food prices witnessed recently. The same situation rears its head in Mamre. The question is then how to incentivise residents to install energy efficiency improvements in order to gain the benefits in the long run and reduce their energy bills, whilst improving their health.

Spalding Fetcher et al (2001) undertook a CBA of various interventions against a consumer discount rate of 30%; the discount rate is higher than the standard 8% due to the high cost of capital these residents face, with loan sharks and short-term lenders taking advantage of their circumstances. The capital subsidy required was the difference between the incremental capital cost of the efficiency intervention, and the PV of the future savings, valued at the consumer discount rate of 30%. Ceilings required a capital subsidy of R481 in Cape Town, R530 in Johannesburg and R461 in Durban. This averages R490 for the ceiling intervention subsidy per NCH across the provinces. If the municipality supplied a R490 subsidy, it should incentivise residents to build ceilings as the benefits accrued over 50 years would outweigh the costs.

Spalding Fetcher et al (2001) found that a R1,000 subsidy in 2001 would make the entire intervention package attractive to most households. At an inflation rate of 6% for 12 years, this would equate to R968 for the ceiling retrofit and R2,012 for the full package of interventions in the Western Cape (in 2013 Rands).

If the 2013 Mamre survey data from above is used, an intervention subsidy amount that would make the ceilings attractive to the Mamre residents can be obtained. The benefits from energy savings, carbon savings, health savings and job creation were taken and discounted by 30%. This provided a PV of R8,932 (B:C of 0.99). If the cost of installing a ceiling is taken at R9,052, the subsidy from the Western Cape Government would need to be R120 per NCH in order to make it attractive and incentivise residents to install ceilings. For the energy savings alone, a subsidy of R7,710 per household would be required, with a B:C of 0.15. This is looking at incentives from a purely financial perspective, whereas a subsidy may not actually lead to a ceiling retrofit uptake due to the number of additional factors not accounted for.

6. Lessons learnt

Having looked at the installation of ceilings in depth, the lessons to be learnt are substantial. Firstly, ceilings are only part of the story. RDP houses are often poorly built, with substandard insulation, floors, walls, doors, windows and ineffective aspect (north/south facing).

Secondly, ceilings are an effective and cost efficient way to improve health and energy efficiencies, as shown by the CBA. This development-focused approach has proven to be invaluable with noteworthy benefits created through a relatively small intervention. It allows one to recognise that state-of-the-art, renewable and green projects should prioritise the needs of the people that they are benefitting, ahead of macro-level and headline-making improvements. Although substantial effort was made in the fieldwork to avoid raising expectations with regard to obtaining ceilings, the Mamre community are pro-active and optimistic for further retrofitting. In order to prevent confusion, clear communication about future ceiling retrofits is needed from the Western Cape Government. The way forward for Mamre is to advocate for funding to retrofit the remaining 160 RDP houses.

The following improvements could be considered for future ceiling retrofit studies:

- The spot reading results could be enhanced with a different methodology. In the data analysis, one could look at improvements by taking readings over a longer period of time in fewer houses, equally distributed between CRHs and NCHs. Highly specified air particle, humidity and temperature machines could be temporarily installed in the houses, rather than taking daily readings with a portable device across a larger sample. This could result in more consistent and accurate long-term readings.
- This study could be compiled over a few months in both winter and summer. This could measure the additional cooling benefits of ceilings, which are not included in this study.
- The temperature differentials could be more exaggerated if the readings were taken in the middle of the night rather than in the morning and evening.
- In the survey analysis, one could look at incorporating the number of sick days off work and schools as part of the survey questionnaire.
- The scope of some health questions in the survey could be increased by creating more options for specifying the illness frequency.
- Another opportunity to improve the study could be to increase the sample size of the houses surveyed.
- It is also recognised that household characteristics between the two types of houses, NCH and CRH, may have differed slightly.

- Household income could have been measured as this could influence the health and energy patterns between the houses, although the census confirmed an equitable distribution in this community

7. Conclusion

The South African state-run housing programme is both ambitious and optimistic in its goals to provide low-cost housing for the previously disadvantaged. However, with an immense backlog in the provision of Reconstruction and Development Programme (RDP) housing and increasing urbanisation, the state's ability to fulfil its targets and promises by the proposed deadlines is highly unlikely. Against this backdrop, the quality of the already built low-cost houses has come under the spotlight. Amongst the numerous faults and quality issues surfacing in RDP housing, one area of concern is the lack of ceilings. This paper has focused on one area in particular, the small town of Mamre in the Western Cape, where the condensation problem has a dramatic negative effect on energy usage and health.

Armed with a qualitative and quantitative survey of a small sample of low-cost houses in Mamre, the benefit of the ceilings in terms of energy, environment and health was established. Ceilings do assist in raising the indoor air temperature by up to 2°C, but play little role in reducing humidity or CO_2 levels. To improve these factors would require better ventilation and damp proofing of the houses. When viewing the results on energy savings, residents with ceilings require less electricity for warmth. The ceilings thus play a significant role in assisting in energy efficiency, with an average saving of R376 per household per year in energy consumption. Regarding health, ceilings also reduce the number of respiratory and other illnesses, ascertained by a statistically significant lower frequency of medical visits per year. This equates to approximately 4.5 less medical visits per year per household or a 39% difference for CRHs. Furthermore, it improves living conditions, has aesthetic and therefore emotional benefits, increases the productivity of residents and provides carbon emission savings, all for a low initial once-off cost.

After conducting a Cost-Benefit Analysis for the Ceiling Retrofit Households, the combined Net Present Value for health, carbon savings, job creation and energy savings was calculated as R24,112 per household. Thus, the motto of the Mamre study is that ceilings act as *heat medicine.* The temperature differentials make a significant difference in the quality of lives for low-cost house residents, presenting a substantial savings for residents and a net benefit for the state.

With 40,000 RDP houses in the Western Cape still requiring ceiling retrofits, a macroeconomic assessment revealed a net overall benefit, economically and environmentally, for an installation roll-out. Equipped with these results, the case for a provincial retrofit programme for all RDP houses that require ceilings (and those yet to be built) is firmly made.

8. References

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103. **9. Annexures**

9.1. Survey questionnaire and data sheet

Survey for Thesis

Address:

Type of House: Ceiling / Non-ceiling (circle)

Contact name and number:

Date:

Number in survey:

1. How many people stay in your household?

2. How many elderly (above 60) are there in the household?

3. How many under the age of 18 are there in the household?

4. Have there been any extensions or renovations other than a ceiling to the house?

5. How many rooms are there in the house?

6. What do you use to cook with day to day? Tick more than one if need be
   □ LP Gas □ Electricity □ Firewood □ Paraffin □ Coal

7. What do you use to warm the house with day to day? Tick more than one if need be
   □ LP Gas □ Electricity □ Firewood □ Paraffin □ Coal
   □ Other:

4. What problems do you experience with this fuel? Tick more than one if need be

   □ Coughing □ Children drink it □ Explosions
   □ It smells bad □ Expensive

5. How often have you used these methods to warm up the house this winter (May-Aug)?

	Coal	Paraffin	Electricity	LP Gas	Firewood	Blankets
More than 5 times a day						
Between 2 and 5 times a day						
Once a day						
Twice a week						
Once a week						
Once every two weeks						
Once a month						
Never						

6. How often have you used these sources of fuel to cook this winter (May-Aug)?

	Coal	Paraffin	Electricity	LP Gas	Firewood
More than 5 times a day					
Between 2 and 5 times a day					
Once a day					
Twice a week					
Once a week					
Once every two weeks					
Once a month					
Never					

7. How much do you spend on average for fuel for cooking and heating per month during summer and winter? If over R300 please indicate the amount.

	Winter (May-Jun-Jul-Aug)		Summer (Nov-Dec-Jan-Feb)	
	heating	Cooking	Heating	Cooking
R30<				
R31-R100				
R101-R200				
R201-R300				
R300>				

8. Would you say this is more, less or the same than you used to spend in FUEL FOR HEATING before you got the ceiling

more than before	same as before	less than before	Uncertain/not sure

9. What are the most common illnesses in your household? Please explain

10. How often (on average) do people in your household suffer from cold, flu, coughing, TB or other respiratory illness?

Very often (3 or more times/year)	Often (twice per year)	Not a lot (once per year)	Hardly ever (can't remember last time)

11. What do you think are the main causes of suffering from respiratory illnesses?

12. How many of your household are being treated for TB?

13. How many times per year do people in the household seek treatment for respiratory illnesses? Treatment can include self-medication, pharmacy assistance, private doctor and others (Please tick √)

Never	< twice/year	2-4 times/year	5 or more times/year

14. How often do you and your family get medical care for respiratory illnesses from the following sources per year?(Please tick √ and write the number of visits)

doctor	Traditional healer	Community	Clinic	Pharmacy	Self-medication	Hospital

15. How often (in average) do people in your household suffer from chest, nose congestion and sore throat as a result of indoor pollution?

Very often (3 or more times/year)	Often (twice per year)	Not a lot (once per year)	Hardly ever (can't remember last time)

16. Do you think respiratory illnesses in your household have increased, decreased, or remained the same since you got the Ceiling? (Please √)

Increased	Decreased	Remained the same

17. How important is it for you to have proper ceilings so that your household keeps cool in summer and warm in winter?

□ Very important □ somewhat important □ Not very important □ we don't care

18. Explain your answer above? I.e. how does or do you think a retrofitted ceiling can improve or not improve your living conditions?

19. What rand amount in energy, heat and health savings do you think a ceiling retrofit is worth per year?

20. What do you think are other reasons behind poor health and energy conservation in RDP houses? What can be done to improve it?

Measurements:

Morning reading (7am – 11am) Time:…………

	Minimum	Maximum	Average	Live
Temperature				
Humidity				
CO				
CO2				

Evening Reading (7pm – 9pm) Time:…………..

	Minimum	Maximum	Average	Live
Temperature				
Humidity				
CO				
CO2				

Interviewer / Supervisor pledge: I certify that this interview has been completed in full with the respondent and according to the instructions I received from Sean Kirsten and it has been thoroughly checked. Interviewer name…………………………………….Signed …………………………….

Back checked: yes/no Date:

9.2. Consent form

Consent Form

I,………………………………………………living at………………………………………………………hereby consent to give access and allow Sean Kirsten and his co-workers to collect data, surveys and information from my household for the duration of this UCT Masters experiment in RDP houses.

I will not hold them liable for any damages or incidents occurring while conducting their experiments

I understand all responses will be confidential and used for the purposes of this research only and that this is a voluntary study.

Signed………………………

Date…………………………….

9.3. Letter of introduction to residents

School of Economics
University of Cape Town
Private BagX3
Rondebosch 7701
SOUTH AFRICA
Telephone: +27 21 650 2723
Fax: +27 21 650 2854
E-mail: Anthony.Black@uct.ac.za

Dear Resident

Sean Kirsten, a postgraduate student at the University of Cape Town, is conducting a research study under my supervision to determine the health and energy impact of ceilings in RDP houses. We will be measuring the impact with a hand-held device that will take the temperature, humidity, CO and CO_2 levels in your house. The aim is to take 3 readings in a day to get an average for your house. This will entail 3 interruptions on a specific day. We will also be asking a few questions via a questionnaire that we request you answer as accurately as possible.

Our intention is to see if there is a difference in temperature, energy usage, humidity, CO and CO_2 between RDP houses with ceilings and those without. We will be reporting our findings to the City of Cape Town to try motivate for the installation of ceilings in houses which do not yet have them. This research has been approved by the UCT Commerce Faculty Ethics in Research Committee.

Your participation in this research is voluntary. You can choose to withdraw from the research at any time. The questionnaire will take approximately 10 minutes to complete and the readings approximately 10 minutes.

Due to the nature of the study you will need to provide the researchers with some form of identifiable information, however, all responses will be confidential and used for the purposes of this research only.

On completion, a short report on the project will be made available to all participants. Should you have any questions regarding the research, please feel free to contact the researcher, Sean Kirsten, on 073 2351872 or by email slkirsten@gmail.com

Thank you very much for your participation in this study.

Yours Sincerely

Professor Anthony Black

9.4. Fluke machine

Source: http://www.measuregroup.co.za

9.5 Statistics

Question 2: Do residents without ceilings have more medical visits?

```
                      Estimate Std. Error t value Pr(>|t|)    
(Intercept)             9.6804     1.0989   8.809 2.36e-11 ***
ceil$treatnon-ceiling   3.6633     1.7516   2.091   0.0422 *  
ceil$old               -0.9329     1.8332  -0.509   0.6133    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5.759 on 45 degrees of freedom
Multiple R-squared:  0.08859,   Adjusted R-squared:  0.04808 
F-statistic: 2.187 on 2 and 45 DF,  p-value: 0.124
```

Question 1: Is there a significant temperature difference between houses with and without ceilings?

a. Evening temperature difference

```
Coefficients:
                      Estimate Std. Error t value Pr(>|t|)    
(Intercept)             2.3517     0.2035  11.557 3.36e-15 ***
ceil$treatnon-ceiling  -0.7675     0.3234  -2.373   0.0219 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.096 on 46 degrees of freedom
Multiple R-squared:  0.1091,    Adjusted R-squared:  0.0897 
F-statistic: 5.631 on 1 and 46 DF,  p-value: 0.02188
```